UNITED STATES DEPARTMENT OF AGRICULTURE

DEPARTMENT BULLETIN No. 1374

Washington, D. C. ▼ March, 1926

STUDIES OF THE PINK BOLLWORM IN MEXICO

By

W. OHLENDORF, Plant Quarantine Inspector
Federal Horticultural Board

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Bulletin No. 1374, United States Department of Agriculture, "Studies of the Pink Bollworm in Mexico," by W. Ohlendorf.

CORRECTION SLIP.

Page 3, line immediately below legend of Figure 2. For "San Carolos" read "San Carlos."

Page 8, Fig. 4. After the first sentence the legend should read, "Top row shows type of winter cocoons, and bottom row type of summer cocoons."

Page 14, Table 13, sixth column. For "2.0" read "20."

Page 24, line 1. For "Figure 3" read "Figure 9."

Page 24, line 6. For "these" read "there."

Page 35, line 3 from bottom. For "infested" (last word in sentence) read "parasitized."

Page 38, line 22. For "20 weeks" read "two weeks."

Page 59, Fig. 15. For "Average number of worms per acre" read "Average number of worms per boll."

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INCEPTION AND SCOPE OF THE WORK[1]

Since its introduction into Mexico in 1911 the pink bollworm[2] has established itself firmly in the Laguna district and has made its appearance in several less important cotton-growing sections in Mexico, as well as at several points in the United States. The United States Department of Agriculture began research work on the pink bollworm in the Laguna district of Mexico in 1918. The results of the work of 1918 and 1919 were reported by Loftin, McKinney, and Hanson.[3] After an interruption of one year the work was resumed in March, 1921, at a new station at Tlahualilo, Durango, Mexico, on a large cotton plantation.[4]

In considering the results of the research work dealt with in this report, it must be recalled that the climate in the Laguna district (fig. 1) is very dry, the average annual rainfall being only about 8

[1] This report is based on two years' work in the Laguna, conducted by the Federal Horticultural Board under the authority given, in the appropriation for the eradication of the pink bollworm, to investigate in Mexico or elsewhere the pink bollworm as a basis for control measures. This investigation has been conducted under the general direction of the chairman of the board and W. D. Hunter, a member of the board. In accordance with the policy established by this board with respect to any research work on insect pests which it becomes necessary for the board to conduct, the results of this investigation are presented as a contribution through and in collaboration with the Bureau of Entomology. The field and laboratory work has been under the charge of W. Ohlendorf, assisted at various times by the following agents of the Federal Horticultural Board: F. F. Bibby, A. C. Johnson, C. R. Roitsch, R. B. Lattimore, J. C. Woodward, W. R. Sudduth, and D. M. McEachern.

[2] *Pectinophora gossypiella* Saunders.

[3] U. C. Loftin, K. B. McKinney, and W. K. Hanson. Report on investigations of the pink bollworm of cotton in Mexico. U. S. Dept. Agr. Bul. 918, 64 pp., illus. 1921.

[4] Special thanks are due the Tlahualilo Agricultural & Colonization Company for extending all facilities that could in any way assist in the research work. To the Testamentaria de Carlos Gonzales also thanks are due for many courtesies extended in connection with numerous observations made in fields on their properties, as well as to many other planters in the Laguna district who at all times willingly cooperated in any investigations made in the district generally. The Comision Inspectora de Plagas at Torreon, charged with the enforcement of the regulations of the Mexican Government relating to the pink bollworm, cooperated in a most satisfactory manner. This commission is under the direction of Dr. R. Ramirez of Mexico City, with Juan Antuna in charge at Torreon.

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inches. Cotton production is possible only by irrigation, and owing to lack of reservoirs the irrigation water which comes from the Nazas River must be put on the land whenever the water is available. As the greater part of the irrigation water usually arrives in the fall and winter, the general practice is to flood the fields (fig. 2) to a depth of from 1 to 3 feet at that time of the year. This often represents all the water that the following year's crop receives except for what little rain may fall during the growing season.

The work of 1921 and 1922 supplemented that of 1918 and 1919. As the life history and the habits of the pink bollworm under Laguna conditions were rather thoroughly studied in the previous research work, the greater amount of attention during the last two years was devoted to studies aimed more directly at control.

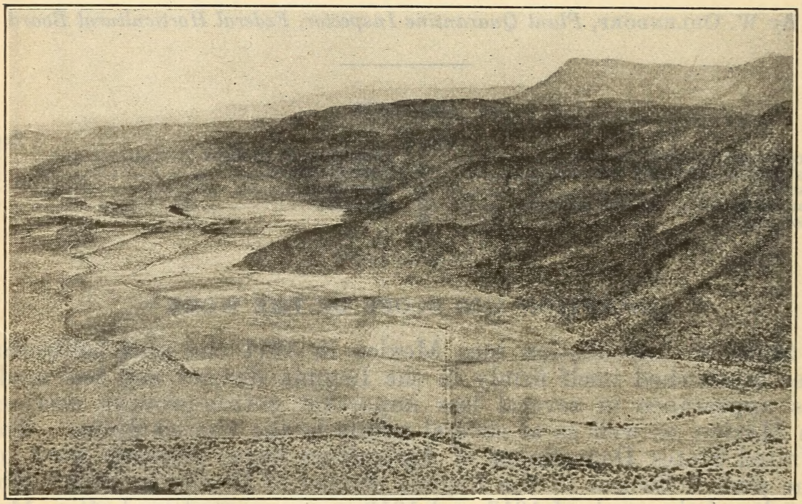

FIG. 1.—Typical Laguna district scenery, showing character of country surrounding the valley

DISTRIBUTION OF THE PINK BOLLWORM

Since the report on the 1918 and 1919 work was published, new and important records of the occurrence of the pink bollworm in various parts of the world have been made. The species is now known to occur in India, Palestine, Mesopotamia, Ceylon, Burma, Siam, Straits Settlements, China, Japan, Korea, the Philippine and Hawaiian Islands, East Africa, Zanzibar, Egypt, Sudan, West Africa (southern Nigeria, Angola, Sierra Leone), Italian Somaliland, Brazil, West Indies, and Mexico, and in Texas, New Mexico, and Louisiana in the United States.

The occurrence of the insect in the West Indies is of special interest. It was first reported from Montserrat and St. Kitts in November, 1920. Later it was reported from Anguilla, St. Croix, and Porto Rico. In July, 1921, it was reported to occur throughout the Leeward and British Virgin Islands, but not south of Montserrat.

In the United States, progress has been made in the eradication of the insect. There has been no recurrence of the two infestations in Louisiana for two years. The infestation at Hearne, Tex., has not

reappeared since 1917. In 1922 there was no recurrence in the large Trinity Bay area, where all or parts of seven counties were found infested in 1917.

In extreme western Texas and New Mexico, conditions have prevented any attempt toward eradication. The infestation is being controlled, however, by quarantines, the disinfection of all cottonseed, and other means, so that it is still at a low ebb and the danger of spread from this area to other parts of the country has been minimized.

DISTRIBUTION IN MEXICO

A new infestation has been found in Mexico, at Monclova in the State of Coahuila. The previously known infestations in Mexico were the entire Laguna district, Santa Rosalia, State of Chihuahua,

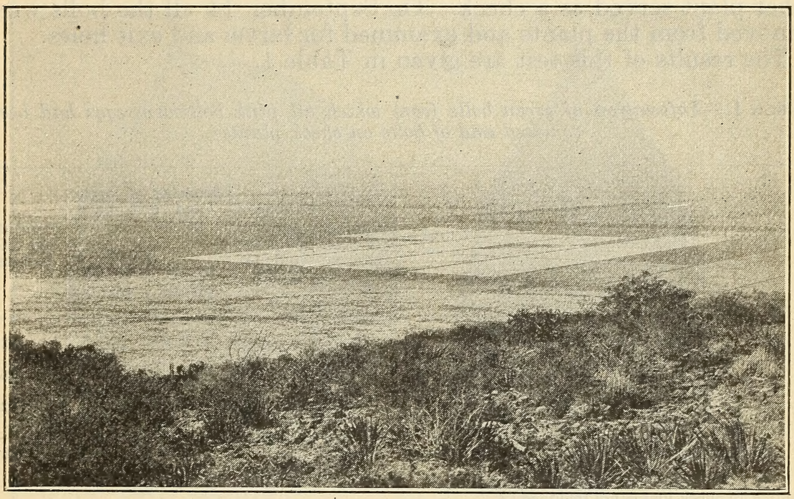

FIG. 2.—Distant view of cotton plantation in the Laguna district, showing flooded fields.

San Carolos, approximately 40 miles west of Eagle Pass, Tex., Allende and Santa Monica in the State of Coahuila, about 40 miles from the nearest point on the Rio Grande, and several points in the Rio Grande Valley opposite Presidio County, Tex., and El Paso County, Tex.

The Mexican records to which reference has been made deal only with infestations in growing cotton. The insect is constantly being brought to the border towns in Mexico in cottonseed scattered in freight cars, and living specimens are frequently found under such conditions by the inspectors of the Federal Horticultural Board.

HABITS

POSITION OF EGGS ON THE PLANT

According to observations made by Loftin [5] on plants growing in the field in the Laguna, 51.7 per cent of the eggs of the pink bollworm are deposited on the green bolls, the remainder on other parts of the

[5] U. C. Loftin, K. B. McKinney, and W. K. Hanson. Op. cit.

plant. Willcocks [6] on the other hand reports only 12 per cent of the total eggs deposited on the bolls in Egypt, stating, however, that these data are based on too few records. No doubt the percentage of eggs deposited on different parts of the plant depends to a great extent on the state of growth of the plant and the ratio of bolls to foliage.

In the summer of 1921 observations were made on plants growing in the field to determine the number of larvæ reaching the bolls from eggs deposited on parts of the plant other than the bolls. These tests were begun August 20. Three sets of plants, two plants per set, were selected, and all bolls then on the plants were removed. Thus the bolls as well as the larvæ considered in the experiment were produced after the experiment began. After a sufficient number of bolls were set, no more were allowed to form. Every two days all eggs were removed from the bolls on one plant in each set. The other plant served as a check. On September 14 all the bolls were removed from the plants and examined for larvæ and exit holes.

The results of this test are given in Table 1.

TABLE 1.—*Infestation of green bolls from which all pink bollworm eggs had been removed and of bolls on check plants*

Plant No.	Number of bolls	Number of eggs removed	Total number of larvæ and exit holes	Number of larvæ and exit holes per boll—		Percentage difference
				Test plants	Check plants	
1	19	1,326	104	5.47		2.3
2	15	0	84		5.60	
3	18	722	111	6.17		26.5
4	18	0	151		8.39	
5	11	741	51	4.64		52.0
6	12	0	116		9.67	
Average per boll		[1] 58.1		5.54	7.80	28.9

[1] Bolls on check plants not included.

The most striking points about these results are the great number of eggs removed per boll and the comparatively little reduction (28.9 per cent) in infestation brought about thereby. The proportion of eggs deposited in other places than on the bolls is likely to have been higher in the case of these plants than is normal, because of the limiting of the number of bolls that grew on them. Considering, however, Loftin's [7] figures (51.7 per cent), first referred to, it would appear that even with only an equal chance for the larvæ hatching from eggs on the bolls to enter the bolls, the infestation should be reduced by at least 50 per cent by the removal of all eggs from the bolls.

From these observations it must be assumed either that the position of the egg on the plant has little to do with the ability of the young larva finally to enter the bolls, or that in this particular experiment, with such a number of eggs present, many of them were so near the bolls that the young larvæ hatching from them were in almost as favorable a position as those hatching from eggs on the

[6] F. C. Willcocks. The insect and related pests of Egypt. Volume I. The insect and related pests injurious to the cotton plant. Part I. The pink bollworm. 335 pp., illus. Cairo. 1916. (Sultanic Agr. Soc.)

[7] U. C. Loftin, K. B. McKinney, and W. K. Hanson. Op. cit.

boll itself. The great excess of the number of eggs on the bolls above the number of larvæ in the bolls shows that the failure of many young larvæ to enter the bolls must be assigned to causes other than distance from the bolls at time of hatching.

The favorite position of the eggs on the bolls is between the wall of the boll and the calyx. A cluster of eggs in this characteristic position is shown on the calyx of the boll in Figure 3.

ENTRANCE OF THE YOUNG LARVA INTO THE BOLL

The entrance hole made by the young larva into the boll is very small but quite distinguishable. Numbers of these punctures are shown on the boll in Figure 3. The young larva seems to show no

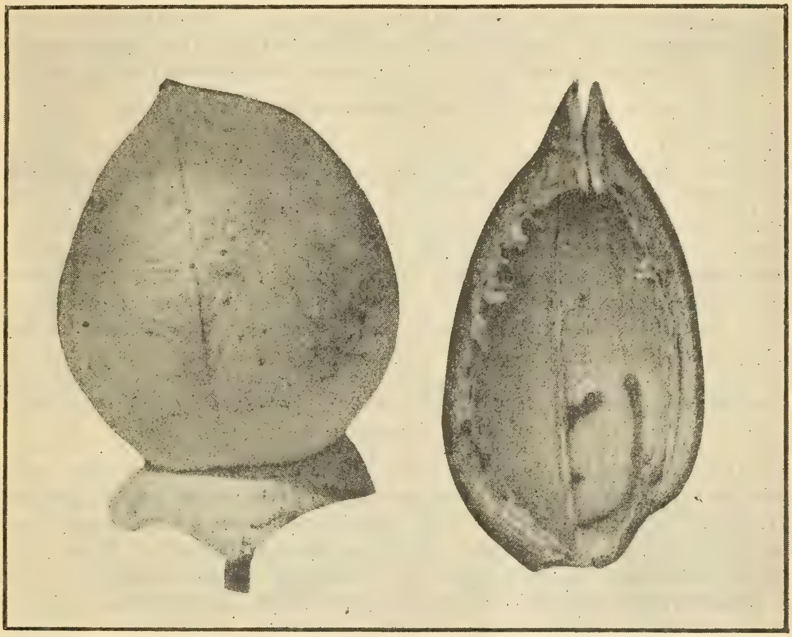

FIG. 3.—Work of pink bollworm on cotton boll. At left: Cotton boll showing entrance holes of young pink bollworm larvæ and cluster of eggs on calyx. At right: Carpel showing characteristic tunneling by young larvæ under inner surface of wall before entering lock

particular preference as to where it attempts to enter the boll. Some counts were made on October 11 and 14, 1921, to determine whether any appreciable number of larvæ enter the boll at points covered by the calyx. The results are shown in Table 2.

TABLE 2.—*Punctures by the pink bollworm under the calyx and at other points on the boll*

Number of bolls	Number of entrance holes—				Percentage under calyx
	Under calyx	Above calyx	Total	Per boll	
89	113	5,678	5,791	65	1.95

The great number of punctures counted on the bolls is very striking. These particular bolls were not examined further to determine the number of larvæ inside, but three field examinations made on October 5, 13, and 20, respectively, gave an average of 5.64 larvæ and exit holes per boll. So it may be assumed that the infestation of the bolls on which Table 2 is based was somewhere near this figure.

In some cases the young larva goes directly through the entire wall of the boll and into the lock of cotton inside. In this case the point where it passed through the inner wall is only slightly raised and may be somewhat colored. Very frequently, after passing through the greater part of the wall of the boll, it tunnels for some distance just underneath the inner surface of the wall. In this case the tunnel usually extends until either the suture or the partition wall is reached, at which point the larva then enters the lock. This tunneling occurs more commonly in nearly mature bolls, where the inner wall is harder. Some of these types of entrances are shown in Figure 3.

ISSUANCE OF FULLY DEVELOPED LARVÆ FROM BOLLS

In the fall of 1922, a test was conducted in the laboratory to determine the time of the day mature larvæ leave the green bolls. Fifty green bolls were placed in a screen-bottom tray, with a trap underneath to catch any emerging larvæ. All larvæ were removed from the trap each day at 8 a. m. and at 8 p. m. Of 172 larvæ taken out of the trap from September 29 to October 17, 160 were removed in the afternoon and 12 in the morning. According to this, the larvæ, at least under laboratory conditions, prefer to leave the bolls during the daytime.

TRANSFORMATION AND HIBERNATION OF THE PINK BOLLWORM IN THE SOIL

PUPATION DURING SUMMER

In the Laguna district the pink bollworm passes the pupa stage during the summer in shed blooms and bolls, under or attached to leaves on the surface of the soil, and in the soil. Rarely are pupæ found in bolls on the stalks. None were ever found in green bolls. One hundred and seventy-four open bolls on stalks examined during the period from July 7 to November 28, 1921, showed neither pupæ nor pupal cases, but a total of 358 larvæ and exit holes. The last figure, however, does not represent the total infestation, since larvæ issuing from the bolls after opening do not as a rule cut exit holes through the wall. Open bolls on stalks during the latter part of November and in December, 1922, averaged about 8 pupæ and pupal cases per hundred.

VARIATIONS IN NUMBERS IN THE SOIL

A considerable number of field examinations were made during 1921 and 1922 in a study of the transformation of the pink bollworm in the soil. In making these examinations, samples of soil, usually 1 square yard to the depth of 6 inches, were taken from heavily infested cotton fields and the number of pink bollworms in each sample determined. The square yard was laid off so as to have a row of cotton running through its middle. The soil was first sifted through a sieve of which the mesh was too small to allow the passage of pink bollworms. The coarse remaining material was taken to the laboratory and washed through other sieves, leaving finally only

particles of plant material and other coarse matter, which was allowed to dry and was then examined. In examinations where forms on the plants and on the surface of the soil were considered, only those forms on the same square yard as that in which the soil sample was taken were included.

Table 3 gives a record of the number of pupæ found in and attached to forms on the surface of the soil, and in the soil. The totals, 34 and 136, show that the larva prefers to enter the soil for pupation.

TABLE 3.—*Pupæ of pink bollworm (live and dead) found per square yard in forms and plant material on the surface of the soil and in the soil*

Date	On the surface	In the soil
1921		
July 21	2	7
Aug. 4	29	96
Sept. 6	2	28
25	1	1
Oct. 18	0	0
29	0	2
Nov. 28	0	2
Total	34	136

DEPTH TO WHICH LARVÆ ENTER SOIL

Larvæ often enter the soil to a depth of 6 inches, but the majority are found within the first 2 inches. In a number of soil examinations made in 1921 cotton fields, the soil was taken up in three 2-inch layers. A record of these examinations is given in Table 4. As will be noted, 70.6 per cent of all stages are found in the first 2 inches, 21.3 per cent in the second 2 inches, and 8.1 per cent in the third 2 inches.

TABLE 4.—*Total larvæ, pupæ, and pupal cases found per square yard at different depths in the soil*

Date	First 2 inches	Second 2 inches	Third 2 inches
1921			
Aug. 4	101	23	3
19	65	33	17
Sept. 6	50	20	10
Oct. 18	41	2	0
29	15	4	0
Dec. 16	19	9	0
1922			
Jan. 3	25	3	3
20	16	0	5
Feb. 28	7	8	1
Total	339	102	39
Percentage of total	70.6	21.3	8.1

Both larvæ and pupæ are found more abundantly in the soil immediately under the plants than in that between the rows. This is shown by the results of some of the soil examinations made in 1921 cotton fields, in which each square yard taken as a sample was divided into two areas. The first area consisted of a strip immediately under the plants, 1 foot wide and 3 feet long, running lengthwise with the row, and the second, 2 strips of the same size as the first and on either side of it. The inner area was thus only half as large as the outer. Table 5 shows the results of these examinations, 67.1 per cent of the

stages being found immediately under the plants and only 32.9 per cent between the rows.

TABLE 5.—*Total larvæ, pupæ, and pupal cases found in the soil immediately under the row and between the rows*

Date	Under the row	Between the rows
1921		
Aug. 19	60	55
Sept. 6	69	11
25	18	6
Oct. 18	33	10
29	9	10
1922		
Mar. 23	18	1
Do	28	16
Do	27	19
Do	6	4
Do	13	6
Total	281	138
Percentage of total	67.1	32.9

RESTING-STAGE LARVÆ IN THE SOIL

Not only does the larva of the pink bollworm, in the Laguna district, go to the soil during the summer for transformation into the

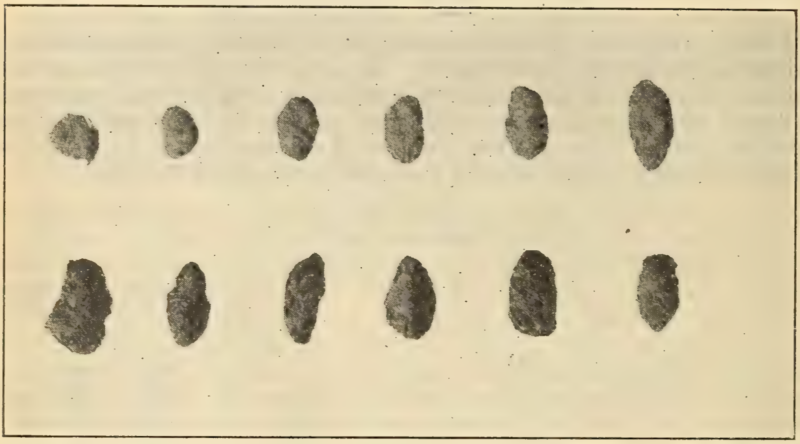

FIG. 4.—Cocoons spun by the pink bollworm in the soil. Top row shows type of summer cocoons and bottom row type of winter cocoons

adult, but to a certain extent it also passes the winter there in the resting stage. The summer larva, after entering the soil, spins a light oblong cocoon in which it pupates. Later, in the fall, some cocoons of a much heavier texture and more spherical in form are noticed in the soil (fig. 4). In these the larvæ are found in the same characteristic curled-up position that they assume on passing the winter in double seeds. Observations have shown that when disturbed, unless it is unusually cold, the larva readily leaves this cocoon.

In Tables 6 and 7 are given the results of all the soil examinations made in 1921 and 1922 cotton fields. The maximum number of living stages found at any time is shown in the second examination of 1921 when a total of 83 living larvæ and pupæ were found in 1 square yard of soil. This sample was taken from a heavily infested field of very large cotton on loose sandy soil.

TABLE 6.—*Soil examinations for pink bollworms, 1921 cotton fields*

Date examined	Number of square yards examined	Living stages found in soil			Dead larvæ and pupæ	Pupal cases
		Larvæ	Pupæ	Total per square yard		
1921						
July 21	1	4	1	5	9	0
Aug. 4	1	9	74	83	24	15
19	1	5	5	10	20	85
Sept. 6	1	44	7	51	24	5
25	1	12	0	12	5	7
Oct. 18	1	2	0	2	0	41
29	1	5	0	5	2	12
Nov. 28	1	27	0	27	3	2
Dec. 16	1	11	0	11	4	13
1922						
Jan. 3	1	15	0	15	6	10
20	1	10	0	10	2	9
Feb. 6	1	15	0	15	5	5
15	1	4	0	4	6	10
28	1	9	0	9	4	3
Mar. 21	[1] 4	33	0	8.25	33	4
23	5	83	0	16.6	49	6
Apr. 17	5	43	0	8.6	18	1
May 1	5	42	0	8.4	20	0
17	5	22	0	4.4	21	1
30	5	16	0	3.2	12	1
June 12	5	9	0	1.8	13	2
26	5	2	3	1	8	5
July 10	5	0	0	0	0	1
24	5	0	0	0	1	0
Aug. 8	5	0	0	0	1	1

[1] This examination and all subsequent ones, except that on Mar. 23, include some samples from plats cultivated in March and April, 1922.

TABLE 7.—*Soil examinations for pink bollworms, 1922 cotton fields*

Date examined	Number of square yards examined	Living stages found in soil			Dead larvæ and pupæ	Pupal cases
		Larvæ	Pupæ	Total per square yard		
1922						
Aug. 8	4	1	0	0.25	1	1
15	4	1	1	.50	2	0
22	4	11	1	3	23	1
29	4	31	1	8	22	3
Sept. 5	4	14	1	3.75	30	5
12	4	31	3	8.5	44	11
21	4	10	0	2.5	7	4
Oct. 7	3.33	15	7	6.6	0	0
23	3.33	11	4	4.5	21	0
Nov. 2	.83	3	0	3.6	4	2
10	.83	4	0	4.8	4	4
17	.83	10	0	12.0	5	9
23	10	52	0	5.2	31	8
Dec. 5	5	108	0	21.6	23	10
13	5	102	3	21.0	29	23
20	5	57	0	11.4	30	3
27	5	103	0	20.6	28	14
1923						
Jan. 3	5	75	0	15.0	23	10
10	5	81	0	16.2	19	16
17	5	66	0	13.2	30	12
24	5	79	0	15.8	21	13
Feb. 1	5	49	0	9.8	30	4
7	5	70	2	14.0	15	18
14	5	57	0	11.4	17	6
21	5	45	1	9.2	30	17
28	5	65	0	13.0	10	22
Mar. 7	5	32	0	6.4	11	12
14	5	62	1	12.6	36	9
21	5	45	1	9.2	20	33
28	5	27	0	5.4	16	20
Apr. 4	5	28	0	5.6	13	24
11	5	22	0	4.4	20	22

It will be noted that the records for 1921 fields show no living pupæ at any time during the period from September 25, 1921, to June 12, 1922, inclusive. This would indicate that any larvæ that enter the soil after about the middle of September prepare to hibernate. No doubt some pupæ were killed by the sifting and washing; but, if any number of living pupæ had been present, some certainly would have been found, considering that during this period 44 square yards of soil were examined and 358 living larvæ found. Some of the larvæ that hibernated in the soil must have pupated long before the time of the first record of living pupæ, June 26, 1922. The records for 1922 show living pupæ in samples of soil as late as October 23, and again on December 13. In fact, there are indications that pupation occurred throughout the winter, and living pupæ were found on February 7 and 21. In another experiment a living pupa was found in a cocoon in the soil on January 22, 1923. The consistent finding of a rather large number of pupal cases throughout December, January, and February, shown in Table 7, also points to some pupation throughout this period.

FIG. 5.—Bolls placed on surface of soil to determine extent to which larvæ will leave these bolls and enter soil for hibernation

NUMBERS OF STAGES IN SOIL AND IN BOLLS ON SURFACE OF SOIL AND ON STALKS DURING WINTER COMPARED

An experiment was begun at the end of November, 1922, to determine the relative importance of soil, bolls on the surface of the soil, and bolls on stalks as hibernating quarters for the pink bollworm. Although this experiment has not been completed and so does not show the results at the end of the hibernating period, it indicates the extent to which the pink bollworm enters the soil for hibernation under the different conditions. Bolls were collected from standing stalks in the field at the end of November. These were divided into lots of 100 bolls each. One lot examined on November 28 showed the extent to which the bolls were infested then. On the following day 15 lots were placed on the surface of the soil in the garden (fig. 5), where there had been no cotton and consequently no larvæ in the soil.

The bolls were placed in a single layer and the lots widely enough separated from one another to allow ample room for the examination of 1 square yard of soil with each lot of bolls. Then, at first weekly and later biweekly examinations of one lot of bolls and the square yard of soil underneath, to the depth of 6 inches, were made, with results as given in Table 8.

TABLE 8.—*Entrance of pink bollworm larvæ from bolls on the surface of the soil into soil for hibernation*

Date examined	Found in bolls			Found in soil		
	Larvæ and pupæ—		Pupal cases	Larvæ and pupæ—		Pupal cases
	Living	Dead		Living	Dead	
1922						
Nov. 28[1]	228	13	11			
Dec. 5	162	12	3	23	1	0
11	152	35	6	9	0	0
18	144	14	1	14	1	0
25	125	25	0	29	3	0
1923						
Jan. 8	143	16	1	12	0	0
22	120	49	0	30	1	0
Feb. 5	76	30	3	14	2	0
20	65	43	1	21	5	0
Mar. 5	[2] 30	[2] 55	1	22	1	0
19	19	60	6	32	4	0
Apr. 2	5	43	3	9	3	0
Averages	94.6	34.7	2.3	19.5	2.0	0
	131.6			21.5		

[1] This represents examination of bolls at start of experiment, as a check, and is not included in averages.
[2] Only 97 bolls in this examination.

The procedure followed in the experiment with bolls or stalks (Table 9) was the same as that in the experiment just described, except that instead of placing the bolls on the surface of the soil they were supported on stakes above the ground in such a way as to represent the same conditions that they would be under were they still on the stalks in the field. These bolls were set out on December 2 and 4 and examinations were made biweekly.

TABLE 9.—*Entrance of pink bollworm larvæ from bolls on stalks into the soil for hibernation*

Date examined	Found in bolls			Found in soil		
	Larvæ and pupæ—		Pupal cases	Larvæ and pupæ—		Pupal cases
	Living	Dead		Living	Dead	
1922						
Nov. 28[1]	228	13	11			
Dec. 7	227	20	12	4	1	0
19	279	7	5	3	0	0
1923						
Jan. 1	285	9	6	2	0	0
16	232	13	5	7	0	0
30	248	17	1	6	2	0
Feb. 13	133	22	4	Ant nest in soil (no larvæ)		
27	130	15	3	1	1	0
Mar. 13	136	24	4	0	0	0
27	131	48	3	3	0	0
Apr. 10	129	29	2	2	1	0
Averages	193	20.4	4.5	3.1	0.6	0
	217.9			3.7		

[1] This represents an examination of bolls at the start of the experiment, as a check, and is not included in the averages.

A very sudden decrease in the number of living larvæ after the end of January without a compensating increase in the number of dead larvæ is noted in both Tables 8 and 9. Few pupal cases were found in any of the bolls, so this does not explain the disappearance of the larvæ; neither was there any increase in numbers found in the soil. On January 30 the first rain, 0.34 inch, fell since the experiment was started. This may have caused many larvæ to leave the bolls; but, owing to the condition of the soil immediately after the rain, they did not enter the soil readily. Many of them were probably destroyed by birds or crawled beyond the area of soil that was examined.

Tables 8 and 9 indicate that very few larvæ left the bolls on the stalks to go to the soil. With the larvæ in the bolls placed on the surface of the soil the proportion leaving the bolls was much greater. As shown in Table 8, most of this entrance of larvæ from the bolls into the soil must have taken place shortly after the bolls were placed on the soil. The first examination, six days after the bolls were placed, showed as many larvæ in the soil as the average for all the examinations. That this may have been due to the heat of the sun is indicated by the experiment about to be described.

EFFECT OF EXPOSURE TO SUN ON ENTRANCE INTO SOIL

On December 11, 1922, 100 bolls were placed on the surface of the soil in each of two boxes filled with soil. One of these boxes was kept in the shade and the other in the sun, both outdoors. Every week the soil was taken from each box and carefully examined for pink bollworms. Fresh soil was then put into the boxes and the same bolls replaced on the surface thereof. The results of this test are shown in Table 10.

TABLE 10.—*Number of larvæ leaving 100 bolls on the surface of the soil in the shade and in sun, and entering the soil*

Date examined	Number of larvæ in the soil: In the shade	Number of larvæ in the soil: In the sun	Date examined	Number of larvæ in the soil: In the shade	Number of larvæ in the soil: In the sun
Dec. 18	0	2	Feb. 26	0	4
25	0	6	Mar. 5	0	1
Jan. 1	0	3	12	0	0
8	0	0	19	0	0
15	0	0	26	0	0
22	0	0	Apr. 2	0	0
29	0	1	9	0	0
Feb. 5	0	2			
12	0	1	Total	0	21
19	0	1			

The total of 21 larvæ found to have entered the soil from the bolls in the sun, with none from the bolls in the shade, shows clearly the effect of exposure to the sun. Below (Table 11) is given a record of the precipitation and the maximum daily temperature reached at the surface of the soil during the time these experiments were conducted, as well as the maximum daily air temperature.

TABLE 11.—*Precipitation and maximum daily temperatures of the air and the surface of the soil.*

Date	Maximum daily temperatures		Precipitation	Date	Maximum daily temperatures		Precipitation
	Air	Surface of the soil			Air	Surface of the soil	
1922	°*F.*	°*F.*	*Inches*	1923	°*F.*	°*F.*	*Inches*
Dec. 11	80	116	0	Jan. 1 to 7	82	120	0
12	80	119	0	8 to 14	82	123	0
13	81	116	0	15 to 21	83	122	0
14	84	124	0	22 to 28	86	128	0
15	81	120	0	29 to Feb. 4	86	127	0.34
16	81		0	Feb. 5 to 11	85	125	0
17	78		0	12 to 18	87	130	0.21
18 to 24	79		0	19 to 25	80		0
25 to 31	79		0	26 to Mar. 4	86		0.15
				Mar. 5 to 11	96		0

THE PRACTICAL IMPORTANCE OF HIBERNATION IN THE SOIL

In a series of experiments reported in Department Bulletin 918,[8] it was found that the survival of the larvæ in the soil is greatly decreased as the amount of moisture increases. In nonirrigated plots it was found that 12.8 per cent of the larvæ were alive or had emerged as moths during May and June, whereas in several irrigated plots no larvæ whatever survived the winter. It was also found that in Mexico the infestation of the season generally starts from material, such as old bolls, left on the surface of the ground. These facts show the reason for the effectiveness of the clean-up measures followed in the United States, where all of the possibly infested material on the surface of the soil is removed and burned and such infestation as remains in the soil dies out on account of the heavy winter rains.

LONGEVITY OF RESTING LARVÆ

Studies to determine the longevity of the resting larvæ were carried on during 1921 and 1922. On March 8, 1921, several thousand heavily infested, open bolls were gathered from standing stalks of the 1920 crop. These bolls were stored in a box in the laboratory, and monthly examinations were made to determine the mortality of the larvæ. In the latter part of the same month several thousand double seed were collected from a large quantity of 1920 seed stored in an oil mill at Gomez Palacio, Durango. These were placed in a cloth bag and stored with a quantity of other seed in a sack in the laboratory. Monthly examinations were also made of these seed.

The results of these studies are given in Table 12.

[8] U. C. Loftin, K. B. McKinney, and W. K. Hanson. Op. cit.

TABLE 12.—*Longevity of resting pink bollworm larvæ*

Date examined	Bolls of 1920 crop				Double seed of 1920 crop			
	Number examined	Number of living larvæ	Dead larvæ and pupæ	Per cent living	Number examined	Number of living larvæ	Dead larvæ and pupæ	Per cent living
1921								
March	100	109	15	87.90	100	29	68	29.89
April	100	48	21	69.56	100	28	58	32.56
May	100	55	25	68.75	100	14	73	16.09
June	100	52	41	55.91	100	4	87	4.39
July	100	28	46	37.84	100	3	89	3.26
August	100	9	64	12.33	100	0	86	0
September	100	2	14	12.50	200	0	196	0
October	100	2	39	4.88	1,000	1	818	.12
November	100	4	64	5.88	975	0	750	0
December	100	1	57	1.72				
1922								
January	100	4	73	5.19				
February	300	1	143	.69				
March	100	[1] 1	50	1.96				
April	600	0	550	0				
May	700	0	481	0				
Maximum longevity	16¾ months.				Maximum longevity	11½ months.		

[1] This larva was placed in a pill box. It pupated and a perfectly developed moth emerged on Apr. 10, 1922.

Some of the larvæ in the bolls survived longer than those in the seeds. The larvæ in both lots of material were attacked by mites, which probably reduced the maximum longevity considerably. In obtaining the figure for maximum longevity given at the foot of the table, the date of the first killing frost in 1920 was used as the starting point.

Table 13 gives the results of the examination of bolls and seed of the 1921 crop. The bolls were gathered in the field on November 11, 1921, and stored on the veranda of the laboratory in sacks. The seed came from cotton picked on November 1 and ginned November 4, 1921. Part of this was stored in sacks in a warehouse, and was examined later as a whole. Other parts were stored over winter in a seed house and in a railroad car, and in the spring the double seed were picked out and stored in glass jars in the laboratory.

TABLE 13.—*Longevity of resting pink bollworm larvæ*

Date examined	Bolls of 1921 crop				Seed of 1921 crop			
	Number examined	Number of living larvæ	Dead larvæ and pupæ	Per cent living	Quantity examined	Number of living larvæ	Dead larvæ and pupæ	Per cent living
1921					*Ounces*			
November	100	296	8	97.37				
1922								
March	15	51	6	89.47				
April	30	39	14	73.58				
May	100	93	59	61.18				
June	95	29	71	29	8	6	94	6
July	67	2	97	2.02	7	2	99	1.98
August	60	0	116	0	1.6	1	218	.46
September	140	1	299	.33	6.5	1	99	1
October	135	1	352	.28	2.0	1	3,608	.03
November	175	1	403	.25	25.5	1	3,382	.03
December	449	1	836	.12	14	1	2,000	.05
1923								
January	700	1	1,366	.07	7	1	1,057	.09
February	1,100	1	2,945	.03	58	1	10,564	.009
March	1,200	1	3,184	.03	9	0	1,658	.0

NOTE.—The first four lots of seed examined consisted of both single and double seeds; the remaining lots consisted entirely of double seeds.

Bolls of the 1921 crop are still available at the present writing (April, 1923), so Table 13 is incomplete, but the records now indicate a longevity of over 16 months.

DAMAGE CAUSED BY THE PINK BOLLWORM

DAMAGE TO IMMATURE FORMS

As pointed out by Loftin,[9] the young pink bollworm often enters a square and reaches maturity therein without causing shedding, and the larva may develop to maturity in the bloom without causing abnormal development of the boll. Just what amount of damage the pink bollworm does by feeding on the immature forms on the cotton plant is difficult to determine, owing to the usual heavy natural shed of forms at about the same time that the pink bollworm becomes very numerous. Under conditions prevailing in the Laguna district during 1921 and 1922, the damage done to squares, blooms, and very young bolls early in the season certainly was entirely negligible This point is brought out in Figure 6, in which it will be noted that the rapid fruiting early in the season quickly outstrips the multiplication of the pink bollworm in the blooms.

Under normal climatic and cultural conditions in this district the fruiting of the cotton is very rapid, once it has well begun. Then a point is reached at which, owing to lack of moisture, all young forms begin to shed off. Later the cotton makes a second growth, which may be very little, or very considerable in case the field receives spring or early summer irrigation. This is illustrated in Figure 6, in which all records after August 21 represent counts in irrigated fields only.

The results of observations on the relation of shedding to infestation made in a field at Tlahualilo during 1922 are given in Table 14. These observations were discontinued early on account of the appearance of the leafworm. The table shows the number of forms on 100 plants on the dates indicated, the number of shed forms found under these plants at the same time, and the percentage of these shed forms that were infested. The field in which these observations were made was cultivated on July 18 and irrigated on July 20. On the 27th it was again cultivated. Many of the shed forms were therefore either covered up or floated away, which made the figure for shed forms on July 29 unusually low, and not representative of the entire shed since July 14.

TABLE 14.—*Relation of shedding of immature forms from cotton plants to pink bollworm attack, Tlahualilo, 1922*

[Number of forms on and under 100 plants]

Date	Forms on plants		Shed forms	
	Bolls	Squares and blooms	Total	Percentage attacked by the pink bollworm
July 14	1,586	712	834	3.5
29	994	49	488	2.5
Aug. 9	947	11	132	4.5
16	1,008	127	10	0
29	1,038	932	12	33.3
Sept. 6	1,162	1,319	36	61.3
14			212	69.8

[9] U. C. Loftin, K. B. McKinney, and W. K. Hanson. Op. cit.

The data in this table are shown graphically in Figure 7. In the graph the figures of Table 14 are reduced to number of forms per plant. A fourth line in the graph shows the development of the infestation in mature green bolls on the plants during the same period of time. A great decrease occurred in the number of forms on the plants between the middle and the end of July. Reference to Table 14 shows that this was due to both shedding and absence of new fruiting. Following the irrigation, however, there was a great increase in fruiting, and shedding practically ceased for a time.

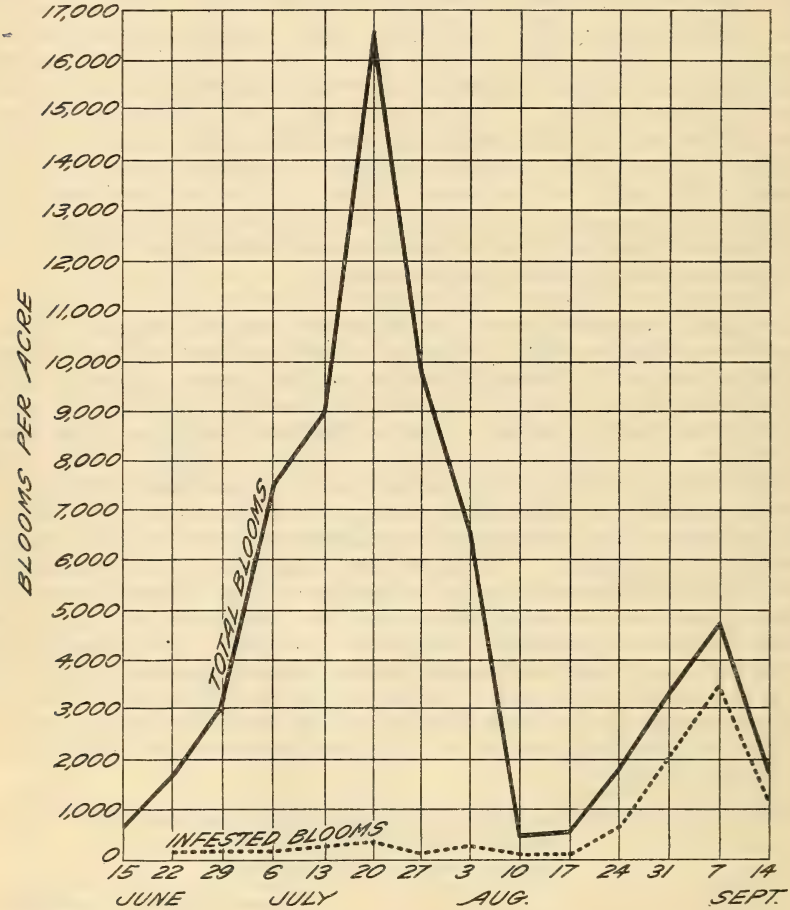

FIG. 6.—Daily average number of total blooms and blooms infested with the pink bollworm per acre, 1921 and 1922 records

The early infestation (fig. 7) was so light that, even if it caused shedding, this could have had no appreciable effect on the total shed, which was very great at that time. During the period of the second growth a much greater part of the shed forms was infested. Comparing this, however, with the infestation of blooms on the plants (fig. 6), it will be noted that an equally high percentage of the blooms on the plants was infested. This indicates that even

at that time little of the shedding of the young forms could be attributed to the pink bollworm.

An experiment was conducted in another field in 1922, in which both infested and uninfested freshly opened blooms were tagged and kept under observation to determine the final percentage of the forming bolls that was shed. Two kinds of infested blooms were considered, those that on the day of opening contained mature larvæ and those that contained immature larvæ. The blooms were tagged on July 19 and 20. In Table 15 are given the results of this test.

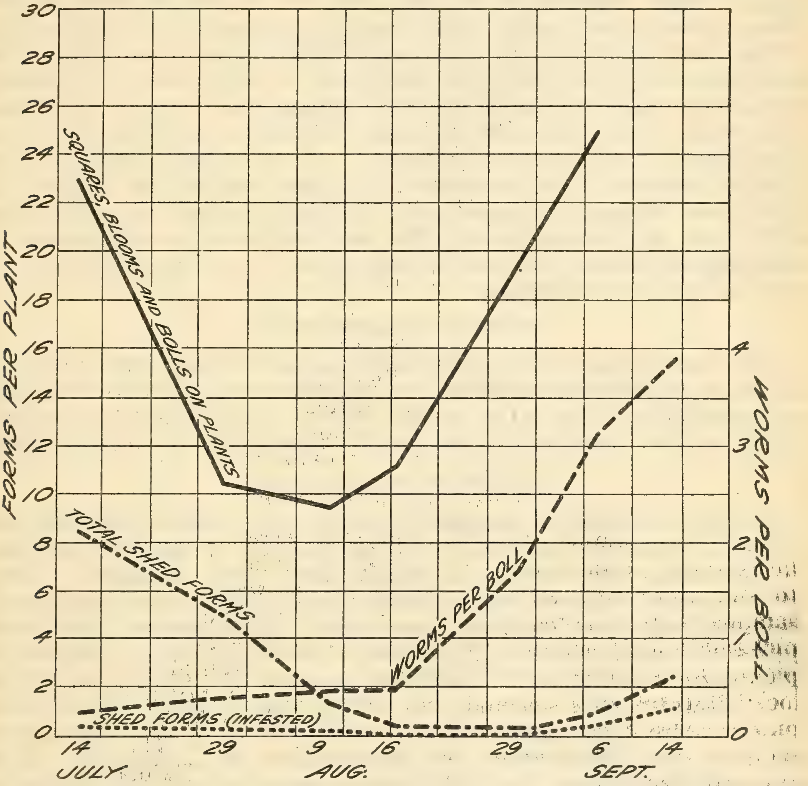

FIG. 7.—Relation of the infestation of immature forms on the cotton plant to shedding

TABLE 15.—*Boll shed due to infestation of the bloom*

Kind of bloom	Number tagged	Per cent of bolls shed
Uninfested	200	61
Infested (immature larvæ)	200	93.1
Infested (mature larvæ)	200	93.74

The only difference noted during the experiment between the shedding of the bolls of the two kinds of infested blooms was that those of the last group in the table were shed sooner than those of the second group. The average of the last two (93.42 per cent)

shows an increase of 32.42 per cent in shedding of bolls of the infested blooms above that of the uninfested.

This does not seem to check with the data on which Figure 7 is based. In that case, as has been pointed out, the percentage of infested blooms on the plants (fig. 6) is equally as great as the percentage of infested fallen forms (fig. 7). These data, however, do not offer a basis for direct comparison. In the first place, the experiments were carried out in two different fields in which the rate of natural shed may have been quite different at the time. Then again, Figure 7 represents all shed forms, not indicating what proportion of them were blooms. And, lastly, it is possible that the feeding of the larva in the bloom may cause bolls to shed even though the larva does not touch the young boll itself, in which case an examination of the shed boll only, after the bloom has dropped off, would not reveal the fact that its shedding was due to the pink bollworm. The figure, 32.42 per cent increase in the shedding of the bolls of infested blooms, or an increase of 53.1 per cent above that of the uninfested blooms, compares with Loftin's figures [10] of a difference of 26.8 per cent in shed due to the pink bollworm, or an increase in shedding of bolls of infested blooms of 65.7 per cent above that of bolls of uninfested blooms.

DAMAGE TO MATURE BOLLS

The damage done by the pink bollworm to bolls that reach maturity has been separated into damage to picked cotton and cotton rendered unpickable. The latter is the cotton which is left in the field by the pickers, because it is too greatly damaged to be worth picking.

DAMAGE TO PICKED COTTON

In 1921 a number of samples of cotton were picked from different fields and experimental plats to obtain samples of lint and seed and to determine the extent to which they were damaged. These samples were obtained by selecting average stalks and picking all pickable bolls from each of these stalks. One hundred bolls were picked for each sample. To obtain a check sample, a number of locks corresponding to 100 bolls and apparently not injured by the pink bollworm were selected, and picked lock by lock. All of these samples were then ginned on a 10-saw hand gin. The damage to the seed was determined by examination at Tlahualilo. After repeated disinfection, the lint samples were sent to the Bureau of Markets at Washington for classification and testing.

DAMAGE TO SEED

From the seed of every one of the above samples a certain volume, averaging about 1,000 seed, was taken. These samples were carefully examined, the damaged seed was separated from the sound seed, each part was counted and weighed, and from these figures the damage was calculated, expressed as percentage of reduction in weight of the samples due to pink bollworm feeding. This method should give approximately the damage to the seed of the picked cotton. The results of this calculation are given in the column under "Percentage reduction in weight" in Table 16. This gives the loss in quantity of seed only. There was in addition a loss in quality, but what this amounted to was not determined.

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[10] U. C. Loftin, K. B. McKinney, and W. K. Hanson. Op. cit.

TABLE 16.—*Comparison of average pick and check samples of lint and seed, 1921 experiments*

Sample or variety No.	Lint												Seed	
	Grade		Length of staple		Uniformity (length)		Tensile strength				Percentage of lint		Percentage reduction in weight	
							Grams		Per cent deviation					
	Check	Average pick	Check	Average pick	Check	Average pick	Check	Average pick	Check	Average pick	Check	Average pick	Check	Average pick
Unirrigated:			*Inches*	*Inches*										
Blue Ribbon	SGM	SGM	7/8	7/8	Regular	Regular	5.12	5.08	40.6	50.6	34.63	38.88	0.81	5.80
019–020	GM	GM	7/8	15/16	do	do	4.83	4.47	43.3	46.1	35.00	33.33	.45	1.07
021–022	MF	GM	7/8	15/16	do	do	5.58	4.78	28.3	37.7	37.21	30.55	.86	5.56
023–024	SGM	GM	15/16	1	do	do	4.67	5.35	41.1	36.1	34.29	30.55	.49	4.76
025–026	SGM	SM	15/16	15/16	do	do	5.02	4.92	43.6	35.5	34.88	34.37	2.85	7.37
Acala	MF	SM	1 1/16	15/16	Uniform	do	4.78	4.65	34.5	46.5	37.50	35.29	.45	4.26
Lone star	MF	SM	1	15/16	Regular	do	3.45	4.20	41.7	47.9	36.36	35.91	.87	5.86
Kasch	SGM	SM	15/16	7/8	do	do	[1] 5.28		[1] 41.9		38.85	40.91	.92	4.71
Truitt	MF	SM	1	7/8	do	do	[2] 4.66		[1] 40.8		37.50	37.98	.19	1.76
Webber-49-3	SGM	M	1 3/16	7/8 to 1 1/8	do	Wasty	4.68	3.25	30.1	44.0	31.25	30.26	.90	4.58
Webber-82-2	MF	M	1 1/8 to 1 3/16	1	Irregular	Regular	5.07	4.77	44.0	45.7	33.33	32.62	.30	3.12
Average			0.9856	0.9375			4.80	4.61	38.6	43.3	35.53	34.60	.83	4.44
Irrigated:														
Express	MF	M	1	1 to 1 1/16	Regular	Irregular	4.45	4.67	30.3	45.8	34.28	32.48	.64	4.40
Acala	MF	GM	1 1/16	1	do	Regular	6.08	5.07	43.3	45.6	33.33	34.30	.37	3.44
Lone Star	MF	M	1	15/16	do	Irregular	5.12	4.97	39.8	36.8	36.36	36.11	1.12	6.80
Kasch	SGM	M	1	7/8 to 15/16	do	do	6.20	5.28	32.6	38.1	40.00	41.21	1.62	4.28
Truitt	MF	SM	1	7/8 to 15/16	do	do	5.87	4.08	45.3	55.4	34.61	36.00	1.03	4.45
Webber-49-3	SGM	M	1 1/4	1 1/16 to 1 3/16	do	do	4.73	3.60	43.3	54.2	31.81	30.57	.73	5.76
Webber-82-2	MF	M	1 1/4	1 1/8 to 1 3/16	do	do	4.10	3.68	40.0	53.5	31.81	31.21	.41	6.58
Average			1.08	1.009			5.22	4.48	39.2	47.1	34.60	34.55	.85	5.10
Grand average			1.02	.96			4.98	4.55	38.9	45.0	35.17	34.58	.83	4.70
Percentage difference			5.9				8.6		15.7		1.7		[2] 3.87	

[1] These figures not included in averages.

[2] Difference in percentage.

NOTE.—All data in the above table, except those in columns headed "Percentage reduction in weight" (of seed), are taken from a report on these samples by the Bureau of Markets, U. S. Department of Agriculture. In their report the following descriptive notes are given: "*Uniformity:* 'Uniform' indicates unusual uniformity in length of fibers. 'Regular' indicates average uniformity. 'Irregular' indicates slightly below average. 'Wasty' indicates mixed length of fiber." The fiber (body) of all samples was classified in the report as "light." "Irrigated" and "unirrigated" in the table refer to early summer irrigation.

As will be noted, none of the check samples were entirely free from pink bollworm damage, the average percentage reduction in weight of seed of these samples being 0.83 of 1 per cent. This was due to the difficulty of determining from outside appearances that locks of cotton actually contained seed that had been damaged by the pink bollworm. The average percentage reduction in weight of the seed (4.7 per cent) would appear rather low. This was to be expected, however, as all the samples were of the first and only picking in the fields from which they were taken, no second crop of any consequence having been produced in these fields. This fact should also be taken into consideration in connection with the data on damage to the lint.

DAMAGE TO LINT

In Table 16 are given the results of tests of the lint samples submitted to the Bureau of Markets.

The first four headings under "Lint" come under "quality," whereas the "percentage of lint" shows the effect of the pink bollworm on the quantity of lint. There is more difference in the case of the unirrigated than in the irrigated cotton. The 1.7 per cent difference, however, is not the entire reduction in quantity of lint. It is based on the actual weight of the seed, and this had been reduced by the pink bollworm. Comparing with the calculated production of lint in the check samples, there is a reduction of the quantity of lint in the samples of average pick of 5.9 per cent. As in the case of the seed samples, however, the lint samples were possibly too small to be considered as accurately giving the lint turnout. This is indicated by the rather wide variations found in some of the samples. The averages given must therefore be considered only as approximations.

NONPICKABLE COTTON

In the foregoing discussion "nonpickable cotton" was referred to as representing part of the total damage done by the pink bollworm to the crop of bolls that actually reach maturity. Nonpickable cotton (fig. 8) is the open cotton left in the fields after the crop has been harvested on account of being too severely damaged by the pink bollworm to be picked. It is expressed as a percentage of the total crop matured and can be determined fairly accurately. In determining the percentage of nonpickable cotton, several representative points were selected in each field, and in 1921 counts were made of all bolls, both picked and unpicked, on a certain number of plants and the number of unpicked locks in these bolls, and in 1922 counts were made of a certain number of bolls both picked and unpicked on consecutive plants and the number of unpicked locks in these. The total bolls and the unpicked locks were then reduced to the same basis, using for the number of locks per boll a figure either arbitrarily set or determined by actual boll examinations in the fields in which counts were made. (In 1921 the first method was followed, the figure used being 4.5 locks per boll; in 1922, using the second method, an average of 4.43 locks per boll was obtained.) From these figures the percentage represented by the unpicked locks is calculated.

In Table 17 are given the percentages of nonpickable cotton separately for the irrigated and unirrigated fields for both 1921 and 1922 and for "zoca" (volunteer cotton) for 1922, based on counts

made in a number of representative plantations in the Laguna. In 1921 the counts were made in November and the first part of December. In 1922 the counts in the unirrigated fields were made in

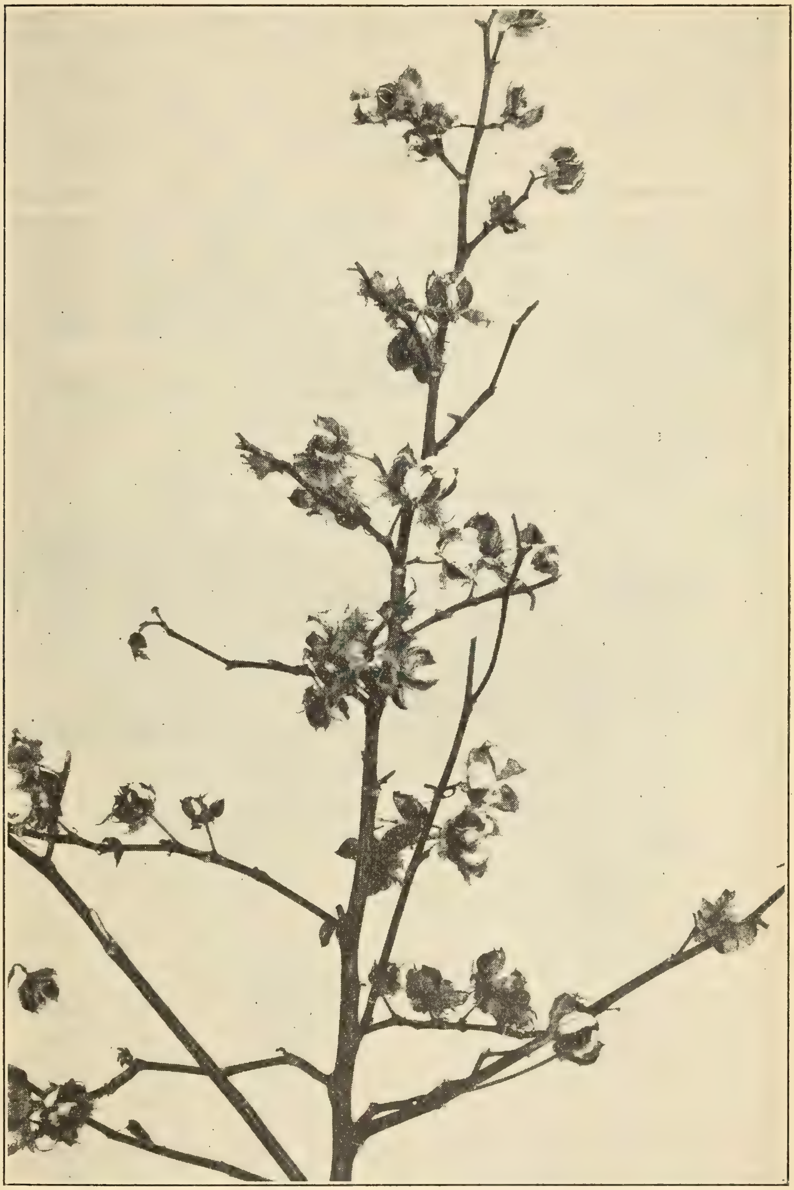

FIG. 8.—Characteristic pink bollworm damage, showing type of bolls classed as "nonpickable"

the latter part of September and the first part of October and those in the irrigated fields during the latter part of November. A frost on October 30, 1921, killed all the cotton and consequently no green

bolls had to be taken into consideration in the counts that year. Frost in 1922, however, did not occur till December 19, and at the time the counts were made that season many nearly mature green bolls were still on the plants. These bolls were recorded at the same time the counts were made, and in this way the figure for "Percentage of crop open" was obtained. The percentage of nonpickable cotton, however, is based on open bolls only. Had the counts been postponed until after the frost, the amount of nonpicakble cotton would have been greater, for many of the green bolls would have had time to open, and they were all heavily infested. This would not have been comparable with 1921, on account of the lateness of frost. As it was, the results for irrigated cotton are more nearly comparable for the two years, since those in 1922 were made not very long after the time of the year when frost occurred in 1921. The extremely low figure for the unirrigated cotton in 1922 can be partly explained by the earliness of the counts. Had these been made at the end of October the percentage nonpickable would have more nearly approached that of the unirrigated fields in 1921.

TABLE 17.—*Nonpickable cotton, Laguna district, 1921 and 1922*

Plantation No.	Percentage nonpickable, 1921		1922								
			Irrigated "planta"			Unirrigated "planta"			"Zoca"		
	Irrigated cotton	Unirrigated cotton	Percentage of crop open	Percentage of open cotton nonpickable	Yield, bales per acre	Percentage of crop open	Percentage of open cotton nonpickable	Yield, bales per acre	Percentage of crop open	Percentage of open cotton nonpickable	Yield, bales per acre
1						80.8	1.33	0.56			
2		7.9									
3			80.9	16.22	0.64						
4		7.9							62.6	2.26	
5		6.1							74.9	10.13	0.12
6		[1] 11.9									
7			97.2	5.00		90.9	3.65	.58			
8		8.0									
9						86.2	5.42		97.9	4.50	
10			94.1	5.34	1.04	91.5	1.40				
11	13.2	6.2									
12	15.2										
13		[1] 13.3									
14		10.3									
15						98.6	1.34	.80			
16			93.1	9.41	1.21						
17		13.9									
18						81.3	.87	.76	70.9	7.66	
19	3.4	7.7	86.0	6.90	.80						
20			54.0	23.59		71.5	7.34				
21						86.0	1.19	.56			
22	14.5					93.9	1.16	.40	51.9	2.60	
23	27.3	14.4									
24									62.7	17.38	
25	16.7										
26	13.9	7.3							82.4	16.03	
27	7.5		96.4	2.04	.75						
28		9.8							90.2	17.18	
29		5.5									
30	29.8										
31	20.8	11.4	97.7	15.99	.79	94.6	3.94	.65	71.3	17.56	.03
Average	16.2	9.4	87.4	10.56	.87	87.5	2.76	.61	73.9	10.59	.07

[1] Zoca fields. "Planta" is planted cotton; "zoca," volunteer cotton.

Average nonpickable, all classes, 1921, 12.8 per cent: 1922, 7.97 per cent.

The great variations shown in the nonpickable cotton on different ranches are due to several things and will be taken up later. One

point of note is the effect an infestation by the boll weevil has on the percentage of nonpickable cotton. This insect severely damaged several fields in 1921. When the attack occurs reasonably early and the weevil becomes abundant, it destroys the greater part of the late crop, allowing very few late bolls to remain on the plant. Then we have a condition represented by a short early crop only slightly damaged by the pink bollworm and very little nonpickable cotton on account of the lack of late bolls. This occurred in the case of plantation No. 19 in 1921, where the percentage nonpickable in the unirrigated field is twice as great as in the irrigated.

RELATION OF THE AMOUNT OF NONPICKABLE COTTON TO TOTAL DAMAGE

A seasonal variation in the ratio of nonpickable cotton to total damage may be looked for, because in seasons of high prices for the staple it will be picked cleaner than when low prices prevail. This variation was illustrated in 1921 and 1922. The infestation on the Tlahualilo plantation, as shown in Table 18, was equally as high in 1922 as it was in 1921, but the percentage of nonpickable cotton on this plantation (No. 31), as shown in Table 17, was 16.1 for 1921 and 9.96 for 1922 (taking the average of the irrigated and unirrigated fields). About the only explanation for this great difference is that the cotton was more closely picked in the latter season, a greater percentage of the severely damaged cotton being gathered and less "nonpickable" cotton left in the field. The price of picking at the end of the season and the price of low-grade cotton apparently substantiate this theory. The lowest grade of cotton (good ordinary) sold for 10 cents per pound during the 1921 season and for 15 cents per pound (Mexico City prices) during the 1922 season. At the same time the highest price paid for picking at the end of the season was 4 cents per kilo in 1921 and 6 cents per kilo in 1922. In this connection is presented Figure 9 to show the relation between nonpickable cotton and the price of cotton.

TABLE 18.—*Progress of infestation of green bolls, Tlahualilo plantation, 1921 and 1922*

Month	Week	Percentage of bolls infested		Number of worms per boll	
		1921	1922	1921	1922
June	Third		22.6		0.22
	Fourth		7.3		.08
July	First		5.2		.06
	Second	17	4.9	0.19	.06
	Third	29	16.3	.45	.23
	Fourth	32.1	15.8	.48	.20
August	First	34.3	27.6	.54	.37
	Second	43.7	31.1	.72	.48
	Third	68.3	59.0	1.57	1.05
	Fourth	87.9	84.1	2.46	2.47
	Fifth	96.4	99.3	3.42	5.13
September	First	95.5	99.9	4.03	6.48
	Second	99.1	100	4.36	7.15
	Third	99.3	100	5.25	7.16
	Fourth	100	100	5.82	6.13
October	First	100	100	5.84	8.57
	Second	100	100	6.98	7.48
	Third	100	100	4.05	5.87
	Fourth		100		4.97
November	First		99.2		4.42
	Second		100		3.16
	Third		100		5.26
	Fourth		100		5.62

In Figure 3 the upper curve represents the percentage of nonpickable cotton on the Tlahualilo plantation for the seasons from 1919 [11] to 1922, inclusive, and the lower curve the average price of "good ordinary" cotton on the Houston, Tex., market during the last three months of the years from 1918 to 1922, inclusive.

TOTAL DAMAGE

For an estimate of the total damage, considering matured bolls only, these are data, other than those showing the percentage of nonpickable cotton, only in the case of the test of seed and lint samples from fields on the Tlahualilo plantation in 1921. Referring to Table 16, there is a reduction in the weight of the seed of 4.7 per cent. In the absence of definite data, let the damage to the lint be considered the same. Figures in Table 17 indicate an average loss in

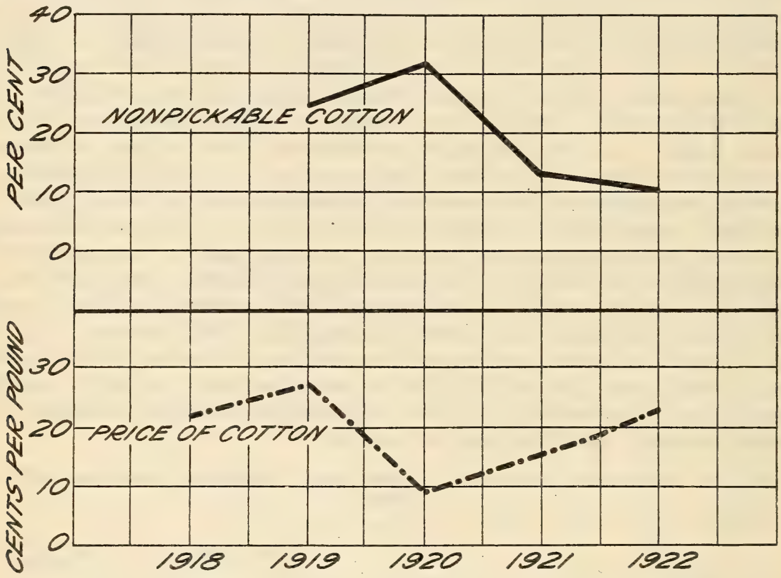

FIG. 9.—The relation between the price of cotton and the amount of "nonpickable" cotton left in the field

1921 on this plantation (No. 31) of 16.1 per cent in the form of nonpickable cotton. This leaves 83.9 per cent representing the crop picked; 4.7 per cent of this gives the damage to picked cotton amounting to 3.9 per cent of the total matured crop, which added to 16.1 gives a total average damage of 20 per cent. In 1921, however, only approximately one-third of the cotton at Tlahualilo received summer irrigation. So a weighted average on this basis, but not considering acreages in individual fields, would give the nonpickable cotton as 14.5 per cent of the total crop, the damage to the picked cotton as 3.9 per cent, and a total damage of 18.4 per cent.

The total loss for 1922 can not be calculated on the above basis, because, as was pointed out before, the figures for the percentage of nonpickable cotton for the two seasons are evidently not comparable.

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[11] The figures for nonpickable cotton for 1919 and 1920 are from Loftin (Dept. Bul. 918 and a subsequent unpublished report by him).

In November and December of 1921, Schutz and Haskell of the Bureau of Markets and Crop Estimates of the United States Department of Agriculture made a survey of the Laguna district, to obtain data on the economic phases of the pink bollworm situation. By the use of questionnaires they obtained from plantation owners and managers data on the average loss due to the pink bollworm. From a total of 143 estimates of the losses during the period from 1915 to 1921, inclusive, they obtained an average yearly loss record of 23.4 per cent of the crop. Their averages were 22.4 per cent for 1921 and 30.4 per cent for 1920, based on 39 and 36 estimates, respectively.

CONDITIONS AFFECTING DAMAGE

SUMMER IRRIGATION

Cotton in the Laguna district which receives summer irrigation is usually more severely damaged by the pink bollworm than unirrigated cotton. The irrigation causes later fruiting, and this late crop becomes subject to attack at the time of the season when the pink bollworm is most abundant. Table 19 shows the progress of the infestation in irrigated and unirrigated fields in both 1921 and 1922.

TABLE 19.—*Average number of worms per green boll in irrigated and unirrigated fields*

Date	1921 Irrigated[1]	1921 Unirrigated	Date	1922 Irrigated	1922 Unirrigated
July 24	0.33	0.57	June 27	0.14	0.03
Aug. 2	.27	.45	July 8	.18	.02
9	.43	.30	18	.38	.11
16	1.22	2.34	28	.36	.14
23	1.81	2.27	Aug. 7	.60	.27
30	2.81	3.63	17	1.85	.77
Sept. 6	4.37	4.08	27	5.05	2.95
13	3.92	3.54	Sept. 5	6.87	4.55
20	5.37	5.20	16	[2] 8.32	
27	6.36	6.16	27	[2] 5.50	
Average	2.69	2.85	Average	1.93	1.10

[1] Dates of irrigation: 1921, July 24; 1922, July 11.
[2] Not included in average.

According to these records the unirrigated cotton in the first part of the season of 1921 was a little more severely infested than the irrigated, but the condition became reversed in the latter part of the season, with a smaller percentage difference. In 1922 the irrigated cotton showed a heavier infestation throughout the season.

A few plantations in the Laguna have wells which supply summer irrigation water. Their irrigation practices differ from those on other plantations in that less water is applied in the fall and winter floodings and several irrigations are given during the summer. Plantations Nos. 16 and 27 in Table 17 are irrigated in this manner. An unusually low figure for the nonpickable cotton on plantation No. 27 is shown in 1921 and 1922. The figure for plantation No. 16 for 1922, however, is not unusually low. Possibly the low damage on the former was due to early maturity of the crops as a whole caused by timely irrigations, which prevented the usually very definite separation between the first and second crops found in fields that receive late irrigation of river water.

DISTANCE FROM COTTON FIELDS OF PREVIOUS YEAR

On the Tlahualilo plantation a system of rotation is practiced in which cotton is not planted on the same land two consecutive seasons. In addition a zoning system has been instituted providing the planting of cotton in fields more or less distant from cotton fields of the previous year. Studies were conducted in 1921 on the influence that distance from source of infestation has upon the damage caused by the pink bollworm. Regular boll examinations were made throughout the season in four selected fields on the Tlahualilo property, located at different distances from 1920 cotton fields. Data on this experiment are given in Table 20. The four fields are hardly comparable in one group, as fields Nos. 1 and 2 were west of old cotton fields and Nos. 3 and 4 were north. But field No. 1 is comparable with No. 2 and No. 3 with No. 4. Only a slight advantage is shown for the more distant fields.

TABLE 20.—*Pink bollworm infestation in 1921 fields located different distances from 1920 fields*

[Worms per boll]

Date	Field 1 (1,000 meters)[1]	Field 2 (2,750 meters)[1]	Field 3 (3,500 meters)[1]	Field 4 (6,250 meters)[1]
June 23	[2] 0.06	[2] 0.09		
30	.01	.015	0.075	0.02
July 8	.008	.024	.037	.002
15	.038	.006	.05	.026
22	.47	.08	.42	.23
29	.44	.15	.45	.35
Aug. 5	.54	.37	.60	.61
11	1.74	.80	1.07	1.12
18			1.74	1.69
26	2.84	3.15		
Sept. 1			3.55	3.32
9	6.02	4.50		
15			5.48	4.34
Averages	1.35	1.01	1.35	1.17

[1] Distance from 1920 fields. [2] Not included in average.

In Table 21 the results of nonpickable cotton counts made in 1921 at 47 different points in unirrigated fields on the Tlahualilo property are presented with reference to the distance of these points from 1920 cotton fields.

TABLE 21.—*Percentage of nonpickable cotton, 1921, in unirrigated fields, with reference to distance from 1920 cotton fields*

Number of points	Distance from 1920 fields (meters)		Percentage of cotton nonpickable	
	Average	Range	Average	Range
34	680	250–1,500	11.5	3 to 32
13	4,730	2,750–6,250	10.6	7 to 16

Here again only a slight advantage is shown in favor of the more distant fields. Comparisons of individual fields in each group bear

this out also. The field in the first group that showed a damage of 32 per cent and another that showed only 3 per cent were both 250 meters from the 1920 fields. Loftin made some counts on this plantation in 1920, and some of his most heavily damaged fields were near fields that showed little damage in 1921.

A relatively heavy infestation was frequently noticed at the edge of a field. This would indicate either migration from a near-by field or possibly greater concentration of moths at the edge of the field on the side toward which flight directed them. The more or less simultaneous beginning of the infestation in different parts of large fields, noted at Tlahualilo in 1921, must be attributed either to a rather general flight of the moths first emerging in the spring or ineffectual fumigation of planting seed. As long as such possibilities remain, the data on distribution of the infestation can not be considered solely with reference to fields of the previous year or seed storehouses as sources of infestation.

VOLUNTEER COTTON (ZOCA)

Under favorable conditions in the Laguna district, volunteer cotton sprouts from stalks of the previous year to such an extent that a considerable crop has often been produced on such fields. This cotton is commonly called "zoca" and its destruction in the spring has in recent years been required by the Mexican Government in its program of pink bollworm control. On account of the extreme shortage of irrigation water in the fall and winter of 1921, the growth and cultivation of zoca was permitted in 1922 in order to offset to some extent the small acreage that could be planted.

The influence which zoca has on the damage of the pink bollworm to planted cotton probably depends greatly on seasonal conditions. With early zoca and late-planted cotton, early food is furnished the worm, and greater numbers of the insects are present when the planted cotton becomes subject to attack than if the zoca is kept down, causing many of the early emerging moths to die without finding cotton on which to deposit their eggs. On the other hand, if the zoca and the planted cotton begin fruiting at about the same time, the former, being on the insects' hibernating grounds, is attacked first and may retard the infestation in the planted cotton. But in that case a rapid increase in the infestation of the planted cotton may be expected when moths in the zoca become so abundant that they begin to seek other cotton.

In referring to the records of nonpickable cotton for 1922 (Table 17), it is noted that the percentage nonpickable for zoca is about the same as that for the irrigated planted cotton and much higher than for the unirrigated planted cotton. Also many more green bolls were left on the zoca than on the planted cotton at the time of the examinations. Ordinarily the stand of zoca is very poor and it has a heavy late growth, which accounts for a high percentage of nonpickable cotton. Although infestation develops early in zoca, it does not necessarily follow that severe damage occurs much earlier than in planted cotton. This is indicated in Table 22, in which the infestation of a field of zoca is compared with the average for three fields of planted cotton on a plantation near Torreon in 1921.

TABLE 22.—*Average number of worms per boll in planted cotton and in zoca, 1921*

Date	Planted cotton	Zoca
June 18	0.14	0.44
July 2	.07	.63
16	.67	1.47
30	1.31	2.79
Aug. 13	1.53	1.95
27	3.20	3.30
Sept. 10	4.08	2.72
26	----------	3.77
Oct. 8	----------	2.02

FOOD PLANTS

Experiments were conducted and observations made by A. C. Johnson on host plants other than cotton to determine the part these plants may be expected to play in the perpetuation of the pink bollworm in the absence of cotton or its spread beyond extensive areas in which there is no cotton. Dry okra plants containing a large number of heavily infested pods were placed under a large screen cage in the winter of 1921–22. The following spring both okra and cotton were planted under this cage, the old stalks being allowed to remain. The cotton bloomed about the middle of June and the okra still later, but no infestation developed on either.

On May 27, 1922, 200 okra pods were gathered from dry stalks that had been in the field all winter. An examination showed 3 living larvæ, 33 dead ones, and 1 pupal case. It is thus evident that under Laguna conditions the larva can survive the winter in okra pods on stalks in the field. In an okra pod, however, the larva is not so well protected against cold as in a cotton boll containing cotton.

Other malvaceous plants growing in the Laguna district were likewise studied with reference to their possible relation to the pink bollworm as host plants. A larva was found in a bloom of hollyhock (*Althea rosea*) as early as May 28 in 1922, and on June 7, 1921. Heavy infestation of hollyhock was never noted, and the larva was observed only in the bloom.

Three wild malvaceous plants are rather common in the Laguna district. These are *Sphaeralcea cuspidata* (Gray), *Sida hederacea* Torr., and *Malva parviflora* L. Quantities of these plants were collected repeatedly and placed in rearing cages, but no stages of the pink bollworm were ever found on them. In many cases these plants were collected immediately adjoining cotton fields. Larvæ of the lepidopteron *Noctuelia rufofascialis* Stephens were found in considerable numbers in the seed pods of these plants. This larva attains practically the same size as the pink bollworm and it is found occasionally feeding on cotton, both in the blooms and in the bolls. The pods of these malvaceous plants are large enough to enable the pink bollworm to reach maturity in them.

A few specimens of *Hibiscus coulteri* Harv. were found on the mountains near Tlahualilo, but they were not infested.

RELATION OF ALTERNATIVE FOOD PLANTS OF THE PINK BOLLWORM TO NONCOTTON ZONES

In the United States in the work of eradicating the pink bollworm the planting of cotton over extensive areas has been prohibited. This work appears to have been entirely successful in bringing about

eradication in several large areas. In these areas, however, no effort was made to eliminate possible alternate food plants.

Very extensive searches have been made in the United States to find infestation by the pink bollworm in okra and other malvaceous plants growing in noncotton zones and in their immediate vicinity. In no case has any infestation ever been found in any of these plants.

The records from Mexico and those from Egypt and other countries have shown clearly that the insect can develop in plants other than cotton. Taking all the available information together, the conclusion seems to be warranted that, in the presence of enormous numbers of the insect, such as are found in Mexico and Egypt, there are occasional more or less aberrant individuals which attack plants other than cotton. With such an attenuated infestation as has occurred in the United States, the volume of the moths is so small that the chance of attack on other plants is negligible.

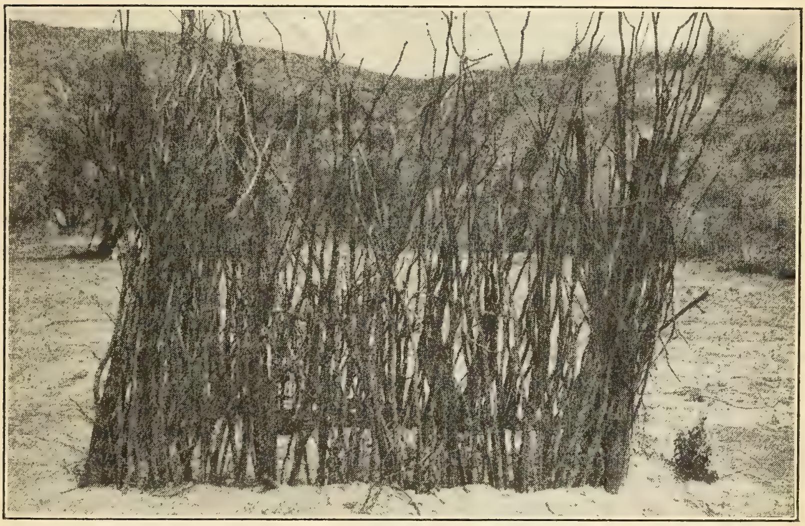

FIG. 10.—Group of cotton plants in tests to determine distance of flight, fenced for protection against animals

DISSEMINATION BY FLIGHT

In 1921 and 1922 F. F. Bibby conducted experiments to determine if possible the distance the pink bollworm moth would normally cover by flight. Small groups of plantings (fig. 10) were made at isolated points distant from cotton fields and kept under observation to determine whether they became infested. Seed free from pink bollworms was used.

In 1921, there were 8 small groups of plants at intervals of 1 mile to the north of the fields on the Tlahualilo plantation, which was the nearest cotton to these plantings. Each group consisted of about a dozen plants, which did not attain any great size and bore little fruit, making examination easy. Thorough examinations precluded the possibility of moths developing in one group of plants and infesting the next one. The results of the test are given in Table 23.

TABLE 23.—*Infestation of plantings in 1921 distance-of-flight tests*

Point	Distance from fields	Date first bloom	Date found infested	Larvæ per group of plants—					Date plants were destroyed
				First instar	Second instar	Third instar	Fourth instar	Total	
	Miles								
No. 1	1	July 19 to 28	Aug. 25	8		1		9	Aug. 30
No. 2	2	July 13	Sept. 22	2	1	1		4	Sept. 22
No. 3	3	Aug. 18 to 25	Sept. 15	7				7	Sept. 18
No. 4	4	do	Sept. 1	1				1	Sept. 7
No. 5	5	Sept. 1 to 7	Sept. 7		2		1	3	Sept. 8
No. 6	6	July 28 to Aug. 4	Oct. 14	6				6	Oct. 14
No. 7	7	Aug. 18 to 25	Sept. 7	1			1	2	Sept. 8
No. 8	8	July 6 to 13	July 28 and Sept. 29	2				2	Oct. 2

All the groups of plants became infested, No. 8, which was 8 miles from the nearest cotton field, being the first. As only one small larva was found in this instance it was removed; but the plants were not destroyed. Close examinations showed that there was no connection between this infestation and the later one in this group of plants. In all other cases the plants were removed soon after the infestation was discovered, and all forms closely examined, with the results given in the table. Each group of plants in this test became infested independently of the others, with the nearest source of infestation as indicated in the table. Whether the moth reached any or all of the points by flight or through carriage by man can not be explained. There was no occasion of infested material being carried past these plantings but the moth may have been carried out in making inspections or by carts which occasionally passed near by. Still, with millions of moths in the fields, it would not seem strange had some of them been carried to these plantings by favorable winds, even though their power of flight is limited.

The following season (1922) plantings of small groups of plants were made in several directions from the source of infestation. Table 24 shows the arrangement of these plantings and the results obtained.

TABLE 24.—*Results in distance-of-flight plantings, Tlahualilo, 1922*

Point	Distance from cotton	Direction	Infestation	Remarks
	Miles			
No. 1	5	North	None	Fruited sufficiently for infestation.
No. 2	8	do	Late	
No. 3	5	West	Early	
No. 4	8	do	None	No fruit formed.
No. 5	5	East	do	Do.
No. 6	6	do	do	Do.

With the exception of the failure of the plants at point No. 1 to become infested, the results are about the same as in 1921.

In addition, two other plantings were made in 1922, one 25 miles northwest and the other 40 miles west of the nearest cotton in the Laguna district. These plantings were on cattle ranches and consisted of about 100 plants each. The first showed as heavy an infestation at the end of August as the average for the Tlahualilo

fields at the same time. The cotton at the other point also developed a heavy infestation. A number of families of Mexicans lived at each of these ranches, and, although supposedly no material subject to infestation was ever brought there, it is extremely likely that infested seed or seed cotton was brought in with packing, bedding, or the like. This seems a more logical explanation, in view of the early development of heavy infestation, than the theory of flight.

NATURAL CONTROL

One of the characteristics of the pink bollworm under conditions in Mexico is the regularity of its attack. Equally as characteristic is the contrast between the enormous number of larvæ found in the fields in the fall and the slow development of the infestation in the spring. Though the latter is probably explained to a great extent by the practice of thoroughly cleaning the fields in the winter and fumigating the planting seed, still were there not a heavy natural mortality among both the hibernating larvæ and the newly hatched larvæ during the season much greater damage would be expected.

MORTALITY OF YOUNG LARVÆ

The great difference between the total eggs deposited and the number of larvæ found in the bolls was pointed out in connection with Table 1. A greater discrepancy occurs between the number of apparent entrance holes on the outside of the boll and the number of worms within the boll, as shown in Table 2. These facts point to a mortality of something like 90 per cent of the young larvæ before they enter the boll.

The mortality of the larvæ after the boll is once entered does not appear to be very high.

Data collected during 1921 on the transformation of the pink bollworm in the soil showed considerable mortality during this period. In a number of soil examinations separate records were kept of the findings in the soil immediately under the plants and those between the rows. For further explanation of this experiment see page 7. In other examinations the soil was divided into three 2-inch layers. The results of the former are given in Table 25.

TABLE 25.—*Mortality of the pink bollworm in the soil immediately under the plants and between the rows*

Date of examination	Under the plants			Between the rows		
	Larvæ and pupæ		Pupal cases	Larvæ and pupæ		Pupal cases
	Living	Dead		Living	Dead	
Aug. 19	7	12	41	3	8	44
Sept. 6	51	15	3	0	9	2
25	10	3	5	2	2	2
Oct. 18	0	0	33	2	0	8
29	2	0	7	3	2	5
Total	70	30	89	10	21	61
Total, all stages	189			92		
Percentage dead			15.9			22.8

A higher mortality among the larvæ and pupæ between the rows than among those immediately under the rows is noted.

Table 26 shows the relative mortality among pink bollworms at different depths in the soil. The mortality is greatest in the first 2 inches of soil, decreasing with the depth. An average for all depths in this table gives 19.7 per cent mortality.

TABLE 26.—*Mortality of the pink bollworm at different depths in the soil*

Date of examination (1921)	First 2 inches			Second 2 inches			Third 2 inches		
	Larvæ and pupæ		Pupal cases	Larvæ and pupæ		Pupal cases	Larvæ and pupæ		Pupal cases
	Living	Dead		Living	Dead		Living	Dead	
July 21	5	8	0	0	0	0	No examination.		
Aug. 4	70	18	13	16	5	2	2	1	0
19	3	17	45	5	3	25	2	0	15
Sept. 6	31	17	2	12	5	3	8	2	0
25	11	3	6	-------	-------	-------	1	2	1
Oct. 18	2	0	39	0	0	2	0	0	0
29	4	2	9	1	0	3	0	0	0
Total	126	65	114	34	13	35	13	5	16
Total, all stages	305			82			34		
Percentage dead	21.3			15.8			14.7		

MORTALITY OF LARVÆ IN THE RESTING STAGE

The pink bollworm larva passes its resting period in or about seed or seed cotton in gins and warehouses, in the bolls in the field, and in the soil. As the activity of the insect lessens in the fall, an increasing percentage of the larvæ spin up in the boll and assume the resting stage. This shows their normal preference for hibernating quarters. Larvæ that hibernate in the soil evidently do so because the boll in which they mature does not offer suitable quarters. It may either still be green when the larva is ready to make its cocoon, or it may have fallen to the ground, where the sun's heat becomes so excessive that the larva enters the soil.

MORTALITY OF LARVÆ IN BOLLS AND SEED IN STORAGE

One hundred bolls collected from standing stalks in the field on March 9, 1921, showed a total of 109 living larvæ and 15 dead ones. Bolls in storage furnish equally as good quarters for the resting larvæ. Of the larvæ in bolls that had been collected from the fields in the middle of November, 1921, and stored, 10 per cent were dead in March, 1922, and in others that were collected early in December, 1922, 7 per cent were dead on February 7, 1923. Usually the larvæ in seed or bolls in storage are attacked by mites, and mortality from this cause rises very rapidly in the spring.

Tables 12 and 13 give records of larvæ in stored seed and bolls of the 1920 and 1921 crops. According to these data, the larvæ survive longer in bolls than in the seed. As all this material was stored under the same conditions in the laboratory, the most likely explanation for the difference is that larvæ in loose seed are more accessible to mites than those in the bolls. The more rapid decrease of the

percentage of living larvæ in the bolls of the 1921 crop than in those of 1920 may be explained in a similar way. The former were stored about four months earlier in the season than the latter and were therefore longer subjected to the attack of mites.

MORTALITY OF RESTING LARVÆ IN THE FIELD

An experiment is now under way which will give data on the mortality of resting larvæ in the field in bolls, both on the stalks and on the soil, as well as in the soil. Data on this experiment are given in Tables 8 and 9. Figure 11 shows graphically the results of the experiments with the bolls on the surface of the soil as recorded

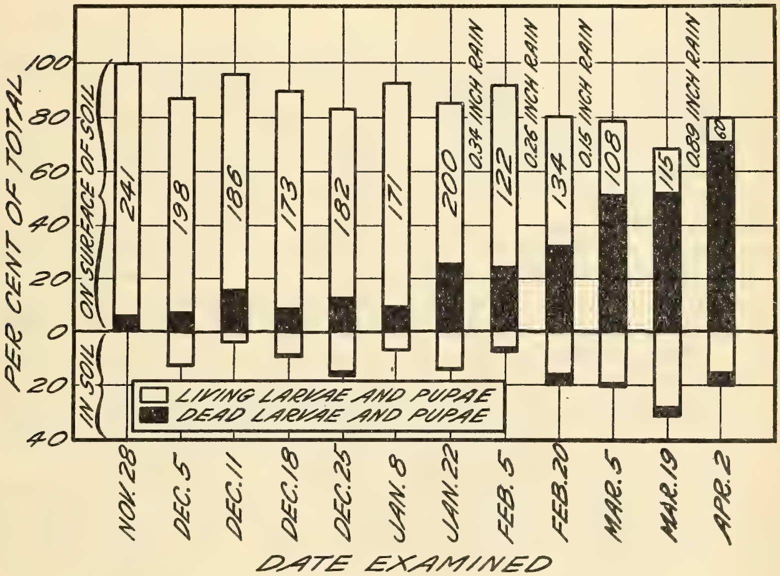

FIG. 11.—Comparative mortality of resting larvæ in bolls on the surface of the soil and of resting larvæ in the soil. Each bar represents the results of the examination of a separate lot of 100 bolls, that had been placed on the soil on November 28, and the soil underneath. The first examination shows the content of 100 bolls at the time they were placed on the soil but before any larvæ had left them to enter the soil

in Table 8, up to April 2. The rate of mortality is seen to be higher in the bolls than in the soil. This diagram does not take into consideration individuals that have emerged. This, however, appears not to have been great to the date of the last record, as will be observed in the record of pupal cases in Table 8. It would appear from this that larvæ left undisturbed in the soil during the resting period have a better chance of surviving than those in the bolls on the surface of the soil at the same time.

Another experiment, conducted in the winter of 1921–22, dealt primarily with the longevity of resting larvæ in seed and bolls on and in the soil of irrigated and unirrigated fields. The results of this experiment are discussed under "Irrigation" as a control method.

In Table 27 are given the percentages of the stages in the soil found to be dead during the winter and spring months in 1921 and 1922.

TABLE 27.—*Mortality of resting pink bollworms in the soil in the fields, 1921 and 1922*

Month	Percentage of mortality	
	1921–22	1922–23
November	10	38.9
December	26.6	22.8
January	24.2	26.4
February	34.9	26.1
March	41.4	33.1
April	29.5	-------
May	39.8	-------
June	60.0	-------
July	100	-------

These records are based entirely on actual field examinations, which explains their irregularity. In the first place there is an accumulation of dead larvæ and pupæ from the summer and fall. And as the larvæ assume the resting stage in the soil gradually, it is not possible to consider a certain percentage of the dead an accumulation of the summer stages and subtract this from all subsequent records. Again, a gradual decay of dead larvæ, which are consequently not found in the examinations, will make the figures for dead too low in the later examinations. Lastly, emergences of moths have not been considered at all in these figures, because pupal cases are to a great extent destroyed in preparing the soil for examination. The records for 1922–23 are based on examinations of more soil than those for 1921–22. Also the soil all came from the same field, which was not the case in 1921–22. Individual figures for the second season are therefore more comparable than for the first. The decrease in the percentage of dead for December, 1922, was due to the cutting of the cotton stalks at the end of November, which, as has been pointed out, caused the shedding of many bolls and a consequent issuance of many larvæ from these bolls and entrance into the soil. From data in Table 7, an increase is calculated in the average number of living larvæ and pupæ per square yard of soil from 6.4 for November to 18.6 for December.

The records in Table 27 give no indication of the total mortality during the resting period and the percentage of the larvæ that finally transform to the moth stage. In connection with an experiment on the effect of winter cultivation, some cages were placed in the field to catch moths emerging from the soil in the spring. This experiment is described in detail in this report, under "Winter plowing." A partly calculated record of an emergence of 2.2 moths per square yard from an uncultivated part of the field which averaged 14 living larvæ per square yard during March and April is given. This would show a mortality of about 84 per cent of the larvæ that pass the resting period in the soil.

PARASITES

In the spring of 1921 an experiment was started to determine whether daily picking of all infested blooms would reduce the pink bollworm infestation. A half-acre plat was selected for this test, and work was commenced June 17. After a few days a considerable

mortality of the larvæ in the picked blooms was observed. This was found to be caused by parasites. Records were then kept of the parasitized larvæ also. The results of this test are shown in Figure 12.

The parasites more or less followed the course of the pink bollworm infestation at first, but afterward did not keep pace with its rapid increase.

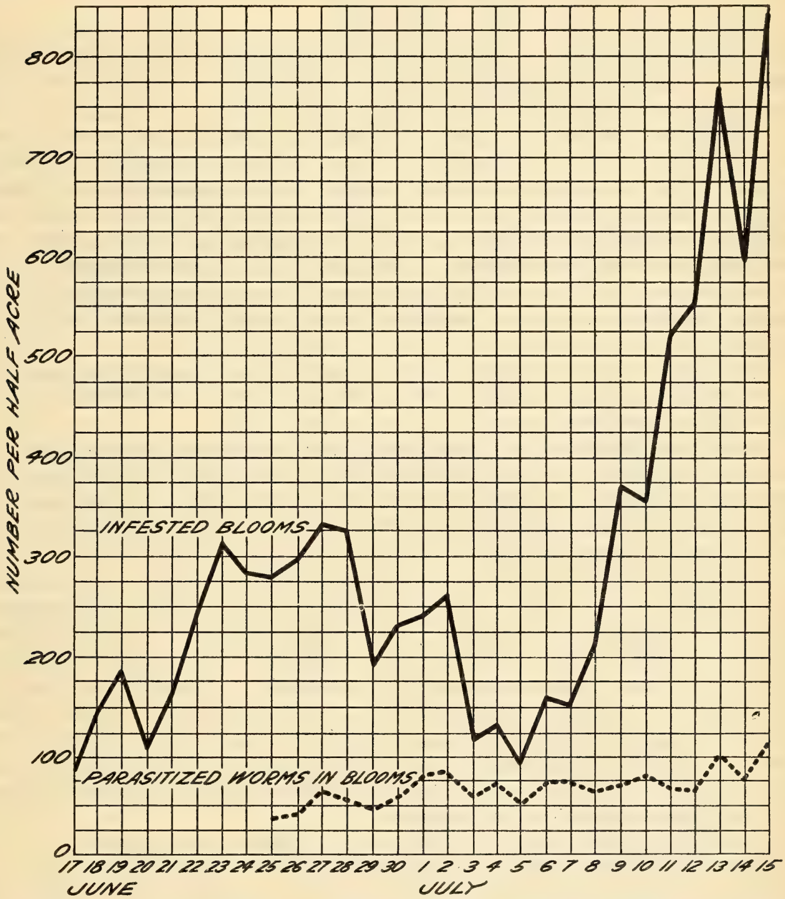

FIG. 12.—Parasitized larvæ in blooms and total blooms infested with the pink bollworm on a half-acre plat, 1921

The peak in blooming was reached on July 11. Regular counts were discontinued after July 15. On July 19 and August 2, two complete counts were made. In the first the maximum of 972 infested blooms and 114 parasites was reached. By August 2 the total number of blooms had dropped to 17 per cent of the maximum, with only 18 infested, and 3 parasitized larvæ. Few parasitized larvæ were found in blooms after this. Of 165 larvæ collected from infested blooms on October 1, none were found to be infested.

Two species of parasites were found to be common. These are *Microbracon mellitor* (Say) and *Habrobracon gelechiae* (Ashm.).

Their life history and habits were studied during the summer by A. C. Johnson and are here given briefly, so far as known.

Normally the female *M. mellitor* stings the pink bollworm larva while still in the square, paralyzing it, and deposits an egg on it. In all cases only a single egg was found on one larva. When placed in a cage the adult did not attack loose pink bollworm larvæ. The larva of the parasite feeds on the pink bollworm until nothing is left of the latter but a mass of dry skin.

The larval period of *M. mellitor* was found in the summer to be from 3½ to 4 days. The pupal period lasted 4 to 5 days. The adult of this species is apparently a nocturnal worker, as none were ever observed in the field in the daytime.

Habrobracon gelechiae is more common through the season than *M. mellitor.* In freshly opened blooms, larvæ of the pink bollworm attacked by this parasite were usually found paralyzed and with the eggs of the parasite on them. This indicates that the attack is made after the bloom opens, which appears likely also when we consider the short ovipositor of the adult. It is common to find 4 or 5 eggs on 1 larva, and as many as 10 have been observed. In some instances the adult attacked loose pink bollworm larvæ in cages.

The larval and pupal periods of *H. gelechiae* are about the same as those of *M. mellitor.* Many adults of the former were observed in the field in the daytime.

About two-thirds of all paralyzed pink bollworm larvæ found in blooms contained neither parasite eggs nor larvæ. It is possible that in such cases the eggs or larvæ were destroyed by other insects, or the adult of the parasite may often sting the pink bollworm without depositing eggs upon it.

On October 2, some clusters of cocoons and several living pupæ of *H. gelechiae* were found in dry blooms collected from the ground. Then 400 closed blooms from 2 to 5 days old were collected from plants. Ninety-seven of these were infested with pink bollworms, of which 10 were parasitized by *H. gelechiae.* About 2 per cent of the larvæ found in bolls in the fields in December, 1921, were parasitized by *H. gelechiae.* These observations show that *H. gelechiae* seems to prefer attacking larvæ in dry blooms and bolls in the fall to attacking them in fresh blooms. During 1921, *M. mellitor* was more abundant early in the season.

Several other species of parasites were reared from pink bollworm larvæ. These were rare and have not been identified.

General observations showed that the parasites were not so abundant in 1922 as in 1921. A few parasites apparently identical with *M. mellitor* were reared from malvaceous plants other than cotton in 1922, but what insects these parasites attacked was not determined. *H. gelechiae* was not observed emerging from these plants.

The more or less spasmodic attack of parasites on the pink bollworm observed in 1921 and 1922 indicates that under conditions existing in the Laguna district no appreciable control of the pest by parasites may be expected, even though a maximum of 33 per cent of the larvæ in blooms early in July, 1921, were parasitized. Climatic conditions are evidently much more favorable for the pink bollworm than for the parasites so far observed.

REPRESSION

CULTURAL CONTROL

The pink bollworm's habit of pupating in the soil during summer, and of passing the resting period there to some extent, suggests that considerable control may be expected from cultural methods designed to kill the larvæ and pupæ in the soil.

IRRIGATION

In the winter of 1921–22 F. F. Bibby conducted an experiment to show the effect of flooding on resting larvæ in the soil. Heavily infested bolls and double seed were placed in a garden under conditions as nearly as possible representing those normally found in the field. The material was arranged in plats part of which could be flooded. In these the seed and bolls were buried at several depths, one layer in the first inch of soil, another 3 inches beneath the surface, and a third 6 inches beneath the surface. A fourth layer was placed on the surface of the soil. The latter material floated when water was applied. One plat of each, bolls and seed, was flooded for a period of 18 days, another for 33 days, and a third for 64 days. Each plat was completely covered with water during this entire time. The floating bolls were kept in water for periods of 18 and 44 days and the seed for 17, 22, 33, and 56 days.

The data obtained in these experiments are summarized in Table 28. In preparing this table the average number of living larvæ found in the seed and bolls when the experiment was started was determined. This was considered as 100 per cent and the percentage of living larvæ and pupæ found in later examinations was calculated on this basis. Forty-seven days after flooding was discontinued on one of the 18-day plats 5 larvæ and pupæ were found loose in and on the surface.[12]

Table 28.—*Longevity of resting larvæ in bolls and seed in flooded and in dry fields*

Approximate date of examination	Time from beginning of treatment to examination	Larvæ surviving in bolls and seed				
		Buried from 1 to 6 inches in soil in field				Floating in water
		In dry plats	In plat flooded 18 days	In plat flooded 33 days	In plat flooded 64 days	
	Days	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Dec. 26	0	100	100	100	100	100
Jan. 15	20	----	----	----	----	17.1
Feb. 4	40	----	----	----	----	.2
24	60	----	7.6	----	----	0
Mar. 6	70	50.9	----	1.2	----	----
26	90	----	----	----	.06	----
Apr. 5	100	----	4.8	----	----	----
15	110	18.4	----	----	----	----
May 24	149	----	1.5	----	----	----
June 3	159	1.5	----	.4	----	----

According to the data gathered in these experiments, the flooding of fields in fall and winter, as commonly practiced in the Laguna

[12] According to Willcocks, irrigation causes larvæ to leave bolls that are buried and seek the surface of the soil for pupation to a greater extent than they do in dry soil.

district (fig. 2, p. 3), whereby the fields remain under water for periods varying from one to two months and sometimes longer, will kill very nearly all the resting larvæ in the soil and in bolls on the surface. The flooding of heavily infested cotton fields just cleared, whenever it can be practiced, should materially retard the infestation in new cotton.

WINTER PLOWING

To determine the effect of winter plowing on resting larvæ in the soil, an experiment was conducted in 1922 in which plats in a field that was heavily infested with the pink bollworm late in the fall of 1921 were plowed in different ways. Five quarter-acre plats were laid off and the following treatments given:

Plat 1: Uncultivated.
Plat 2: Harrowed and cross-harrowed with disk harrow, March 9, 1922.
Plat 3: Plowed to a depth of about 6 inches, harrowed and cross-harrowed with disk harrow, March 9, 1922.
Plat 4: Plowed to a depth of 6 inches, March 9, 1922.
Plat 5: Zoca, soil thrown away from plants with two cultivator shovels, first week of April, 1922.

After this plowing, examinations of 1 square yard of soil to the depth of about 8 inches were made in each of these plats at intervals of about 20 weeks. Plat 5 was not included in the first examination, as it had not then been cultivated. The data obtained in this experiment are given in Table 29.

TABLE 29.—*Effect of different methods of plowing on the pink bollworm hibernating in the soil*

Date examined	Number of pink bollworms found per square yard of soil									
	Plat 1, check		Plat 2, harrowed		Plat 3, plowed and harrowed		Plat 4, plowed only		Plat 5, cultivated	
	Living	Dead	Living	Dead	Living	Dead	Living	Dead	Living	Dead
1922										
Mar. 22	10	5	4	11	3	6	16	11	No examination.	
Apr. 17	18	7	13	7	1	1	9	2	2	1
May 1	8	14	7	2	13	3	6	0	8	1
17	7	7	5	4	7	5	3	3	0	2
30	4	0	1	4	6	7	5	0	0	1
June 12	2	3	2	2	2	4	2	1	1	3
26	0	1	0	3	4	3	0	1	4	0
July 10	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	1	0	0	0	0
Aug. 8	0	0	0	0	0	0	0	1	0	0
Total	49	37	32	33	36	30	41	19	15	8
Average	4.9	3.7	3.2	3.3	3.6	3.0	4.1	1.9	1.67	.89
Percentage dead		43.0		50.77		45.5		31.7		34.8

Considering only the total number of living individuals found per plat, there is a notable reduction in the plowed plats, especially the cultivated zoca. But the two harrowed plats show the highest percentage of dead individuals, and plat 4 is particularly low in this. Considering the individual examinations, the first one shows a very decided advantage for the two harrowed plats. Only 4 and 3 living specimens were found in these, compared with 10 in the uncultivated

plat and 16 in the plat that was plowed only. However, some later examinations show up entirely differently. Thirteen living specimens were found in a square yard from plat 2 on April 17, and the same number in a square yard from plat 3 on May 1. It is evident that further experiments should be conducted.

In addition to the soil examination, three cages were placed on each plat (except plat 5) to catch any emerging moths. Each cage covered 1 square yard and had a trap arranged in the middle to catch emerging moths. Paper covers were placed on the cages at night, leaving only the traps exposed. It was thought that moths seeking light or free air would more readily enter the traps in this way. The cages were examined every second or third day with the following total results:

Plat 1. 2 moths, April 15.
2. 1 moth, April 15.
3. 0 moth.
4. 1 moth, April 30.

In August all these cages were removed and the surface of the soil under each one carefully examined for signs of any moths that might have emerged and not entered the traps. Only the following were found:

Plat 1. 1 dead pupa in cocoon on surface of ground, 1 pupal case under base of cage.
2. 1 pupal case under clod of earth.
3. 1 pupal case under clod of earth.
4. 1 pupal case under clod of earth.

The efficiency of the traps on the cages was tested. One cage was set up as it had been in the field, 20 moths were placed under it in the afternoon, and the paper cover was put on during the night. Only 6 of the 20 moths were found in the trap on the morning following. This indicates that probably only 30 per cent of the moths that emerged under the cages in the field were caught in the traps.

One striking point brought out is the difference between the number of moths that emerged and the number of living larvæ found in the soil. Table 29 gives an average for the first two examinations in plat 1 of 14 living larvæ per square yard. On this plat, in 2 cages, covering a total area of 3 square yards, only 2 moths were caught. If this was 30 per cent of the moths that actually emerged under the cages, there was a total of 6.67 moths, or an average of about 2.2 moths, emerging per square yard.

EMERGENCE OF ADULTS THROUGH SOIL

An experiment was conducted in the spring of 1922 to determine the depth of soil through which a moth can emerge. Two sets of sheet-iron cylinders were made. These were 5 inches in diameter and closed at the bottom and ranged in depth from 4 to 20 inches. Larvæ in cocoons from the soil and in cottonseeds were placed in the bottoms of the cylinders and covered with soil to different depths (see Table 30). The cylinders were taken to the field and sunk in an upright position in the ground so as to leave the surface of the soil in the cylinder on a level with the surface of the soil on the outside. Screen-wire traps were made to fit the tops of the cylinders, so that any emerging moths might be caught.

These cylinders were kept under observation throughout the summer and in October the soil was removed from them and carefully examined. Table 30 shows the results of this experiment.

TABLE 30.—*Emergences of moths and larvæ buried at different depths in soil in cylinders*

Larvæ buried		Emerged during summer			Found in soil (dead)		
Depth	Number	Larvæ	Pupæ	Moths	Larvæ	Pupæ	Pupal cases
Inches							
4	74	2	----------	1	17	3	4
8	74	----------	----------	----------	15	2	3
12	74	4	----------	----------	6	----------	1
16	74	1	1	----------	8	----------	4
20	73	3	----------	1	15	1	6

The larvæ recorded under "Emerged during summer" were found in the traps, evidently having issued from the soil and entered the screen-wire traps in searching for a place to pupate or trying to escape from the cylinders. This also accounts for the one that entered and later pupated. These larvæ and the pupa were all dead when found, having evidently been killed in the traps by the heat of the sun. The adult taken from the cylinder in which the larvæ were buried at the depth of 4 inches was alive and perfectly developed. The other adult was imperfectly developed and had been partly eaten by ants when found.

Considering the number of larvæ that were found to have issued from the soil, the most reasonable explanation of the emergence of the moths is that the larvæ first came to the surface, or near the surface, and then pupated. This explanation is much more reasonable than that a moth could issue from any great depth of soil unless it were of such nature that the moth would not have to burrow its way out. The experiment plainly shows that the pink bollworm, at least in the larva stage, can escape even if buried to a considerable depth by cultivation.

SUMMER CULTIVATION

It was shown in Tables 25 and 26 that during the summer the natural mortality of the pink bollworm in the soil is greater for individuals found between the rows than for those found immediately under the plants and that the mortality decreases with depth. This suggested that the heat of the sun might be responsible for the increased mortality, since larvæ between the rows, particularly near the surface, are more exposed to this heat. A few experiments were conducted to determine whether this is true.

Temperature readings were taken on several days in September, 1921, on the surface of the soil and 1 and 2 inches below the surface during the hottest part of the day. These readings are recorded in Table 31.

TABLE 31.—*Temperature, in degrees Fahrenheit, on surface of, and in, soil between cotton rows in the field*

Date	Hour	Surface	1 inch beneath surface	2 inches beneath surface	Maximum air temperature
1921		° F	° F	° F	° F
Sept. 13	12.30 p.m.	142	124	113	----------
	2.30 p.m.	141	123	112	95
	4.30 p.m.	123	116	108	----------
Sept. 14	10.00 a.m.	128	101	92	----------
	12.30 p.m.	146	115	106	96
	2.30 p.m.	138	124	111	----------
	4.30 p.m.	114	112	110	----------
Sept. 15	10.30 a.m.	128	102	94	----------
	12.30 p.m.	141	114	102	92
	2.30 p.m.	130	112	102	----------

A temperature sufficient to kill the pink bollworm in a very short time is reached on the surface of the soil, and the soil, even as deep as 1 inch below the surface, becomes hot enough on some days to kill in time. All these readings were taken between the cotton rows, where the soil was exposed to the direct rays of the sun.

Early in the morning of September 14, infested blooms were placed in and on the surface of the soil in direct sunlight and in the shade of cotton plants. These blooms had been collected from plants and allowed to dry several days in the laboratory. Ten blooms, each containing a living larva, were used in each experiment. Late in the afternoon the blooms were removed and examined. The results are given in Table 32.

TABLE 32.—*Effect of solar heat on pink bollworm larvæ in blooms in and on the surface of soil in sunlight and in shade*

Location	Sunlight	Shade
On surface	10 dead larvæ	4 live larvæ, 6 empty blooms.
2 inches beneath surface	6 live larvæ, 4 empty blooms	7 live larvæ, 3 empty blooms.
4 inches beneath surface	5 live larvæ, 5 empty blooms	2 live larvæ, 8 empty blooms.

All larvæ on the surface in the sun were killed. All larvæ in the other locations either lived or left the blooms. The maximum air temperature on this day was 96° F.

A similar experiment was conducted a few days later with pupæ in blooms. After exposure the pupæ were removed and placed in vials so that emergences of moths could be noted. The results are given in Table 33.

TABLE 33.—*Effect of solar heat on pupæ in shed blooms in and on the surface of the soil in sunlight and in shade*

Location	Sunlight		Shade	
	Total pupæ	Moths emerged	Total pupæ	Moths emerged
On the surface	14	0	14	9
2 inches beneath the surface	13	10	Test omitted.	
4 inches beneath the surface	12	11	Test omitted.	

If the pink bollworm normally remained in the blooms until they were shed, a considerable number of those in blooms falling between the rows should be killed by the heat of the sun. On September 26 some blooms containing larvæ were tagged for observation, to ascertain whether the larvæ remain in the blooms until they are shed. Some of these blooms were removed from the plants each day and examined, with results as follows:

Sept. 27. 20 blooms removed, 19 contained larvæ.
28. 20 blooms removed, 16 contained larvæ.
29. 20 blooms removed, 9 contained larvæ.
30. 18 blooms removed, 4 contained larvæ.

This shows that normally the majority of the larvæ leave the blooms before they are shed. Thus they may have a better opportunity to seek suitable shelter in the shade of the plants than they would have if they remained in the blooms until they are shed.

It would appear from the results of the foregoing tests that a method of cultivation during the summer in which the top layer of soil is thrown away from the plants might materially increase the mortality in the soil by exposing larvæ and pupæ to the sun. An experiment aimed at this point was conducted during the summer of 1922. Four plats of about 12 acres each were laid off and numbered. Plats 1 and 4 were checks, and plats 2 and 3 were cultivated every 6 days, plat 2 on 1 day and plat 3 on the following day. Cultivators with shovels set so as to throw the soil away from the plants were used. This work was continued from August 4 and 5 to September 14 and 15, a total of 8 cultivations being given each of the plats. When this experiment was begun, regular cultivation had been discontinued, so plats 1 and 4 received no cultivation whatever during this period. A 6-day interval was used between cultivations. This is the minimum pupal period at this time of the year, according to Loftin [13] and the purpose was to stir the soil at least once during the time each individual is in the pupa stage. The pupa would not be able to move about to any extent if exposed to the sun by the cultivator.

A square yard of soil from each plat was examined weekly and a sample of bolls from 2 points per plat every 10 days. The results of these examinations are given in Tables 34 and 35.

Table 34.—*Effect of summer cultivation on the pink bollworm in the soil*

[Living and dead larvæ and pupæ and pupa cases in 2 square yards of soil]

Date of examination	Plats 2 and 3 (cultivated)			Plats 1 and 4 (check)		
	Living	Dead	Pupal cases	Living	Dead	Pupal cases
Aug. 8		1		1		
15		3		1		
22	3	7	1	9	16	
29	18	12		14	10	3
Sept. 5	5	11	1	10	19	4
12	15	20	4	19	24	7
21	7	5	3	3	2	1
Total	48	59	9	57	71	15
Total		116			143	
Percentage dead			50.9			49.6

[13] U. C. Loftin, K. B. McKinney, and W. K. Hanson. Op. cit.

TABLE 35.—*Average number of worms per green boll in cultivated and check plats*

Date of examination	Plats 2 and 3 (cultivated)	Plats 1 and 4 (check)
Aug. 6	0.35	0.19
16	.65	.60
26	2.94	3.58
Sept. 5	5.35	5.86
15	5.86	6.18
25	6.05	6.47
Average	3.53	3.81

Although fewer living larvæ were found in the cultivated than in the check plats, there were also fewer dead ones. The proportion of living to dead was about the same in the two cases.

HEAVY WINTER KILLING IN WET SOILS

Earlier in this bulletin attention was directed to the fact that the survival of larvæ in the soil decreases as the amount of moisture increases. In unirrigated plats 12.8 per cent of the larvæ were alive or had emerged as moths during May and June, while in several irrigated plats no larvæ whatever survived the winter. This heavy mortality in wet or soaked soils during the winter indicates perhaps one of the most important possibilities of control of this pest wherever, through irrigation or the occurrence of winter rains, the soil becomes and remains for considerable periods thoroughly moistened. Under such conditions it seems probable that all of the pink bollworm larvæ entering the soil for hibernation will be killed. On the other hand, it is known that the larvæ in cotton bolls, either on standing plants or on the surface of the ground, survive the winter in large percentages. Such opportunity of carriage of the pest over winter can be very largely eliminated by thorough cleaning in the fields of all cotton plants, scattered bolls, or other rubbish, and the burning of such material. It would appear, therefore, that under the moisture conditions indicated and the thorough cleaning, a method of effective control will be available for irrigated districts and others where the winter rains are adequate to hold the soil fairly moistened for a considerable period. Undoubtedly, the effectiveness of the clean-up measures which have been carried out in the United States in the effort to eradicate the pink bollworm has been due quite as much to the mortality of the larvæ in wet soil as to the thorough collection and destruction by burning of all old plants and scattered bolls. This is particularly true in southeastern Texas and in Louisiana, where the winter rains are heavy.

EFFICACY OF CLEAN-UP METHODS

In the winter of 1922–23 an experiment was conducted to determine approximately what proportion of the resting larvæ in the field are destroyed by cutting and burning the stalks. As pointed out in the discussion of hibernation habits (Tables 7 and 8), many larvæ leave the bolls and enter the soil when the stalks are cut.

A field that was heavily infested late in the fall was selected and on November 23, 2 square yards of soil to a depth of 6 inches were examined at each of five different points. An average of 5.2 living larvæ per square yard were found in this soil. At the same time all bolls on the stalks growing on these 10 square yards of soil were removed and examined. There was a total of 122 dry and 50 green bolls, an average of 17.2 bolls per square yard, and these contained a total of 397 living larvæ (first and second instars not included), or an average of 39.7 per square yard.

At near-by points in this field two areas of 50 square yards each were staked off on November 25 and the bolls both on the plants and on the ground were counted. On November 28 and 29 the stalks were cut, and on December 1 they were raked up. On the following day the bolls on the surface of the ground in the same areas were again counted. The results are shown in Table 36.

Table 36.—*Number of bolls on stalks and on the ground on an area of 100 square yards, before and after cutting stalks*

Bolls	Before cutting stalks		After cutting stalks		Percentage shed in cutting
	On stalks	On ground	On stalks	On ground	
Green bolls	108	3	[1] 77	34	28.7
Open bolls	986	190	[1] 443	733	55.1
Total	1,094	193	[1] 520	767	52.5
Per cent of total on the ground		15.00		59.6	

[1] Calculated.

This shows that nearly 60 per cent of all the bolls were left on the ground after the fields were cleaned, and that 28.7 per cent of the green bolls and 55.1 per cent of the open bolls on the stalks were shed in cutting the stalks. Using the percentage of 15 for bolls on the ground before cutting and the figure of 17.2 bolls on stalks per square yard already mentioned, at the time the soil examination was made on November 23 there were on an average 3 bolls per square yard on the surface of the soil at the points where these examinations were made. On November 25, 100 bolls collected from the surface of the soil showed an average of 2.12 living larvæ per boll, which would make an average of 6.36 living larvæ in bolls on the surface of every square yard of soil. On each of December 2 and 5,100 bolls were collected from the surface of the soil and examined, giving an average of 1.41 living larvæ per boll. And on December 5 another square yard of soil was examined at each of the 5 points where examinations were made before, giving an average of 21.6 living larvæ per square yard in the soil. Then using the figures obtained in these two soil examinations and the percentages given in Table 36, the distribution of larvæ before and after the stalks were cut can be calculated. This calculation is summarized in Table 37.

TABLE 37.—*Distribution of bolls and larvæ before and one week after cutting of stalks in field*

[Number per square yard]

	Before cutting stalks			After removing stalks		
	On stalks	On surface	In soil	Removed with stalks	On surface	In soil
Bolls	17.2	3	----------	[1] 8.2	12	----------
Larvæ	39.7	6.36	5.2	12.76	16.9	21.6
Per cent of total larvæ	77.5	12.4	10.1	24.9	33	42.1

[1] Difference between total of last two columns and total of first three.

Although this summary is a calculation based on several separate observations and must be considered as only approximate, it should be fairly reliable. The figure of 12.76 larvæ removed in 8.2 bolls gives an average of 1.56 larvæ per boll. Usually the larger and better-matured bolls remain on the stalks, and a higher worm content is found in them than in those that are shed. It seems safe to say, however, that in this field not more than from one-fourth to one-third of the total larvæ were destroyed by cutting and burning the stalks. The stalks were cut by hand and raked up with a hay rake. Afterward they were burned.

Soil examinations at the same five points in this field were continued weekly, and at each time 100 bolls were collected from the surface for examination. Table 38 summarizes the results of these examinations, including only those made after the stalks had been cut.

TABLE 38.—*Average number of living and dead larvæ per square yard in the soil and per boll in bolls on the soil after removal of stalks*

Date	Per boll on the surface		Per square yard in the soil		
	Living	Dead	Total living	Total dead	Living in bolls and locks in the soil (average)
Dec. 2	1.3	0.10	----------	----------	----------
5	1.54	.15	21.6	4.1	
13	1.18	.38	20.4	3.6	1.86
20	1.58	.27	11.4	3.6	
27	.82	.14	20.6	3.8	
Jan. 3	.72	.21	15.0	3.4	
10	.62	.15	16.2	3.0	1.4
17	.52	.18	13.2	4.8	
24	.51	.19	15.8	3.4	
Feb. 1	.30	.18	9.8	5.2	----------
7	.23	.15	14.4	2.2	----------
14	----------	----------	11.4	2.8	----------
21	----------	----------	9.2	4.8	----------
28	----------	----------	13.0	1.4	----------
Mar. 7	----------	----------	6.4	1.6	----------
14	----------	----------	12.6	7.2	----------
21	----------	----------	9.2	4.0	----------
28	----------	----------	5.4	3.2	----------
Apr. 4	----------	----------	5.6	2.6	----------
11	----------	----------	4.4	4.0	----------

These data show particularly the effect of pasturing after the stalks were cut. Between December 20 and 27, a herd of cattle was pastured in this field for a number of days. These cattle ate a considerable part of the bolls left on the surface of the soil. They picked up practically all the larger bolls, the sudden decrease in the number of larvæ found per boll on December 27 being due to the removal of the larger bolls, which contained the greater number of larvæ. Apparently there was no increase, or very little, in the number of larvæ in the soil to offset the decrease in living larvæ in bolls on the surface. The figures in the last column, giving the average number of the larvæ in the soil that are found within locks or open bolls, before and after pasturing, show that there can not have been much trampling of bolls into the soil by the cattle.

Early cleaning of fields in the fall, before a great part of the late unpickable bolls open, is recommended. In this way the number of bolls shed would be reduced. Grazing after cutting the stalks should be practiced, if possible, and it is possible that grazing before the stalks are cut is even more beneficial. If the stalks are not cut until all bolls are dry and open, it may even be advantageous to delay cutting until after cold weather has set in and the larvæ have spun up more completely. Then possibly there might not be any appreciable issuance of larvæ from shed bolls and entrance into the soil, and consequent pasturing would destroy a great part of the larvæ in the shed bolls.

TREATMENT OF SEED BY HEAT

Machines for killing the pink bollworm in seed by heat have been in use in Egypt for some years. The Egyptian seed is practically lintless, whereas that produced in Mexico and the United States is covered with lint. For this and other reasons it was necessary to devote considerable attention to methods of treating seed.

Laboratory tests were made to determine the amount of heat required to kill the pink bollworm in cottonseed, and the amount of heat to which seed may be exposed without injury. The latter point was determined by tests conducted by the Federal Horticultural Board at College Station, Tex., where laboratory facilities for this work were furnished by the college. These tests were conducted in February, 1921, with Texas seed. A Freas electric oven was used.

THERMAL DEATH POINT

The tests on the thermal death point were conducted at Tlahualilo, using a Freas oven also. At first several series of tests were conducted in which larvæ in double cottonseed were used. The procedure followed was to bring the oven to the desired temperature, which was maintained by thermostatic control. The seed, arranged in a single layer on a sheet of perforated cardboard, was then introduced. All larvæ upon removal from the seed were placed in pill boxes and kept under observation for several days. One hundred double seed were used in each test.

In one series of tests the seed was heated in dry air, that is, the normal air in the oven. In another series dishes containing water were placed in the oven. Evaporation from this water brought about a moist condition of the air.

The results of these tests are summarized in Table 39. All the tests with dry heat giving 100 per cent mortality, except those from 145° F. down, were repeated three or four times.

TABLE 39.—*Thermal death point of pink bollworm larvæ in double seed exposed to heat in Freas oven, with margin of safety for seed*

Period of exposure	Temperature required to cause 100 per cent mortality		Maximum temperature to which seed may be heated without injury to germination	
	Dry air	Moist air	Dry air	Moist air
Minutes	° *F.*	° *F.*	° *F.*	° *F.*
5	195	160	----------	----------
10	170	145	----------	----------
15	----------	----------	175	170
20	145	135	----------	----------
30	140	130	165	170
45	135	125	----------	----------
60	130	----------	160	160

In the tests with the larvæ in seed more heat was required than Willcocks[14] found necessary in his experiments. With dry air he found a 30-minute exposure at a temperature ranging from 121 to 129° F. to give 100 per cent mortality, and with moist air an exposure for 4 minutes at 159.8°. This difference is probably due to the fact that Egyptian seed is practically devoid of lint.

Following the tests that are given in Table 39, a series of experiments with unprotected larvæ was conducted in the Freas oven. These experiments differed further from the others in the fact that the larvæ were placed in the oven at approximately air temperature, and the temperature afterward raised. Two devices were finally decided upon as giving the most accurate results. The first was to place the larvæ in a cylindrical screen cage with a cardboard floor in the center, on which the larvæ rested. A thermometer was inserted centrally through this cylinder with the bulb partly above and partly below the cardboard floor. This cage with thermometer in position was hung in the oven and kept swinging like a pendulum until the desired temperature was reached. Then it was removed and the larvæ immediately cooled. In the second device the larvæ were placed in a shallow perforated blotter tray in the bottom of which a thermometer rested. The tray was set in the oven and the temperature raised until the desired point was reached. Then the tray was removed and the larvæ immediately cooled. The results of the tests conducted in these two ways are given in Tables 40 and 41.

[14] F. C. Willcocks. Op. cit.

TABLE 40.—*Thermal death point of unprotected pink bollworm larvæ exposed in swinging cage in Freas oven*

Number of larvæ exposed	Cage temperature at start	Time of exposure	Cage temperature at end	Mortality
	°F.	*Minutes*	°F	*Per cent*
10	88	13¾	135	60
8	80	11½	135	62.5
10	85	6¼	135	50
10	77	15¼	140	100
10	81	14½	140	100
10	80	13¾	140	100
10	82	10	140	100
10	82	9¾	140	100
10	83	9	140	100
10	84	8	140	100
5	81	7¼	140	100
10	80	7¼	140	100
10	83	7	140	100
10	82	7	140	100
10	86	6¾	140	100
10	83	7	140	100
10	84	6¼	140	100
10	82	6½	141	100
8	82	19	145	100
10	92	10¼	145	100
10	87	7¾	145	100
10	85	6¾	145	100
10	84	6	145	100
10	79	18½	150	100
10	84	7½	150	100
10	84	5½	150	100

TABLE 41.—*Thermal death point of unprotected pink bollworm larvæ exposed in blotter tray in Freas oven*

Number of larvæ exposed	Temperature in tray at start	Time of exposure	Temperature in tray at end	Mortality
	° F.	*Minutes*	° F.	*Per cent*
8	81	16½	135	87.5
7	91	13½	135	100
9	101	8½	136	100
8	81	18¾	140	100
10	90	12¼	140	100
7	100	11¾	140	100
8	99	10¼	100	100
8	100	8½	140	100
11	101	8½	140	100
10	102	8¼	140	100
8	102	8¼	140	100
9	100	8	140	100
9	90	12¾	142	100
10	99	9½	142	100

The air in the oven during all these experiments was dry. The thermal death point as indicated by these tests is 140° F., or between 135 and 140° for the conditions under which these tests were made. The results agree closely with those of Willcocks.[15]

COMMERCIAL DISINFECTING MACHINES

From the writer's experiments it appeared that the heating of cottonseed to a temperature sufficient to kill the pink bollworms contained therein and at the same time not to injure the seed, would be comparatively simple. The main difficulty in perfecting a com-

[15] F. C. Willcocks. Op. cit.

mercial machine was to obtain capacity equal to the output of an average gin and still to maintain the machine on an economical and effective basis. This matter was taken up actively by R. E. McDonald, of the Texas Department of Agriculture, and owing to his efforts rapid progress has been made in developing satisfactory machines.

Machines developed in the United States may be grouped in two general classes according to the principles on which they operate. In the machines of one group the seed is heated by hot air and to some extent by contact with heated parts of the machine. Machines of the other group inject live steam into the seed mass itself. Tests were conducted with one machine of each group at Tlahualilo, in 1922.

DRY HEAT PROCESS

In January, 1922, the Texas Department of Agriculture sent a machine of the dry-heat type to Tlahualilo and tested it there. This machine consisted of a large drum containing a group of steam pipes, all fixed on a central axle. It is set at a slight angle, and on operation the entire machine, drum and pipes, revolves. Flanges on the inside of the drum carry the seed up and drop it between the steam pipes. The seed moves forward through the drum on account of the tilt of the machine. As a result of exhaustive tests, McDonald and Scholl [16] reached the following conclusion: "Our tests indicate that cottonseed uniformly exposed to dry heat for three and one-half minutes and discharged at 145° F. will be rendered free of living pink bollworms." They found further, from numerous experiments detailed in their report, that injury to germination begins at a certain temperature which is somewhere near 165° F.

It should be mentioned that tests with commercial machines and laboratory tests in an electric oven do not give data directly comparable. In the practical operation of a disinfecting machine, the machine temperature will necessarily vary according to the temperature of the seed before treatment and the quantity of seed that passes through the machine at any one time, the object of course being to heat all the seed to a required temperature. Consequently the temperature of the seed on discharge must be used as the basis in the data obtained. With the laboratory tests, an oven in which constant temperature could be maintained was used, and the quantity of seed in any one test was so small that no accurate discharge temperatures were obtainable. Therefore, in these tests the oven temperature forms the basis of comparison.

The Texas Department of Agriculture left its machine at Tlahualilo when its tests were completed. Later, to reinforce the data, the writer independently conducted similar tests with the same machine.

In these tests seed taken directly from a seed house was used. It was fed into the hopper by hand. Irregularity in feeding is partly responsible for the irregular discharge temperatures obtained and the differences in steam pressure required to bring the seed to a certain temperature. A sample of from 1 to 2 bushels per test was caught as it came out of the machine and spread immediately on a wire screen, so that it cooled as quickly as possible. After cooling, all

[16] R. E. McDonald, and G. J. Scholl. Disinfecting cotton seed to prevent the spread of the pink bollworm. Texas Dept. Agr. Bul. 71, pp. 38, illus. 1922.

double seed and locks of cotton were picked out of this sample and examined for pink bollworms. The larvæ found were removed from the seed and kept in pill boxes for a time to make certain that none revived.

Results of one set of tests are given in Table 42.

TABLE 42.—*Tests conducted with a dry heat disinfecting machine for destruction of the pink bollworm in cottonseed*

[Time of exposure ranging from 2⅓ minutes to 6¾ minutes]

Test No.	Steam pressure	Time of exposure	Number of larvæ in test	Temperature of seed on discharge	Mortality	Germination
	Pounds	*Minutes*		° *F.*	*Per cent*	*Per cent*
212	8- 4	2½-6	25	141 -136	100	----------
237	16-15	3 -6	34	138 -137	91.2	----------
216	15-11	2½-5½	29	142.5-138	93.1	----------
207	20-30	2¾-6	21	141 -138.5	90.5	----------
214	21-23	3 -6	25	141 -139	100	----------
233	11- 9	3 -6	26	139.5-139.5	100	----------
234	15-21	2¾-6	16	139.5-153	100	----------
217	20-20	3 -6	22	140 -140	86.4	----------
238	22-21	3 -6¼	29	143.5-140	100	----------
243	20-21	3 -6½	25	140.5-141	96	----------
218	20-21	3 -6	21	141 -144.5	100	----------
244	22-22	3 -6½	24	143 -142.5	100	----------
220	20-18	3 -6	27	143 -143	100	----------
242	18-18	2¾-6½	23	144 -143	100	----------
221	27-25	2½-6	26	146.5-143	100	----------
231	15-17	2½-6¼	23	143 -148	100	----------
229	14-17	2½-6	27	143 -153	100	----------
215	20-19	2¾-6	28	147.5-143.5	100	----------
211	24-22	2¾-6	25	148.5-144	100	----------
219	20-35	3 -5½	25	144 -149	100	----------
213	18-16	2½-6	22	146 -145	100	75.5
240	25-27	3 -6½	27	145 -146.5	100	75.0
236	15-21	2¾-5¾	33	145 -156	100	70.5
239	25-25	3¼-6¾	37	146 -145.5	100	81.0
222	26-26	3 -6	28	148 -145.5	100	71.0
245	22-22	3¼-6¾	30	146 -147	100	80.5
230	20-20	2¾-6	27	148.5-153	100	70.0
226	35-33	2⅓-6⅓	19	151 -149.5	100	73.5
210	25	2¾-6	26	150 -150	100	----------
232	18-18	2¾-6¼	30	150 -151	100	64.0
241	24-25	3 -6½	18	155.5-150.5	100	82.0
228	20-21	2½-6¼	21	150.5-158	100	61.5
209	35-30	3 -6	24	153 -151	100	----------
223	40-41	2½-6	12	154 -151.5	100	71.5
235	33-48	3¼-6¼	20	152.5-169	100	73.5
208	40	2½-6	31	153 -154	100	----------
227	32-33	2¾-6¼	19	156.5-158	100	72.5
224	63-59	3 -6½	28	161.5-163	100	68.0
225	44-40	3 -6	27	163 -166	100	----------
Average						72.6
Average 6 untreated checks						74.8

Steam pressure readings were taken at the beginning and at the end of each test. The difference between the two readings which usually occurred can be ascribed to difference in boiler pressure. The greater pressure required in some tests than in others, though the same discharge temperatures were obtained, was due either to difference in feeding or to absorption of heat by the machine, which usually took place for some time after steam was first applied each day. The time of exposure was ascertained by dropping a handful of colored seed into the hopper while the machine was in operation. The time required for the first and the last of these seed to pass through gave the two readings. Both extremes represent only single scattered seeds, the majority coming out within a period of about one minute. In the column "Number of larvæ in test" are included only larvæ that were alive before the seed was treated. Temperature records were obtained by catching one bucket of seed immedi-

ately before and one immediately after the sample for examination was taken, and determining the temperature of the seed in these buckets. The difference between the two temperatures in most of the tests can likewise be ascribed to differences in feeding and to variations in steam pressure. The temperature readings should more or less represent the minimum and maximum for each sample examined.

Next, a series of tests was conducted in which the period of exposure was decreased by lowering the discharge end of the machine. Otherwise the method of operation was identical with that in the first set of tests. The results are given in Table 43.

TABLE 43.—*Tests conducted with a dry-heat disinfecting machine for destruction of the pink bollworm in cotton seed*

[Time of exposure ranging from 1 minute to 3½ minutes]

Test No.	Steam pressure	Time of exposure	Number of larvæ in test	Temperature of seed on discharge	Mortality
	Pounds	*Minutes*		*Degrees F.*	*Per cent*
256	33–36	1¼–2½	(1)	130 –132. 5	(1)
255	37	1¼–2¼	17	139 –138	70. 6
257	39–39	1¼–2½	20	141 –140. 5	100
252	26–26	1¼–3½	19	141. 5–144	100
258	47–45	1¼–2¼	26	146. 5–143	96. 1
254	40–38	1 –2½	14	148 –143. 5	100
259	49–48	1¼–2¼	36	148 –145	100
253	35–37	1 –2½	32	147 –151	100

[1] No examination.

The result shown in these two tables tends to substantiate the conclusion, drawn by McDonald and Scholl,[17] that seed exposed to dry heat so that it attains a temperature of 145° F. in a period of 3½ minutes is effectively disinfected.[18] That 100 per cent mortality is not obtained by shorter exposures, even though a temperature of 145° is recorded, is no doubt due to the fact that the interior of individual seeds, when immediately cooled, does not attain the temperature recorded by the seed if bulked for a short time after exposure.

LIVE-STEAM PROCESS

The type of machine just discussed, although found to be effective, heats the seed rather slowly. Also, a machine of greater capacity was desired to meet the needs of large gins [19] where the installation of machines of the first type with proper capacity would be an expensive item. To meet these requirements a machine was developed in which the seed is heated by injecting live steam into the seed mass. Much more rapid heating is brought about in this manner. A machine of this type was sent to Tlahualilo and tested by J. C. Woodward.

The machine consisted of three inclosed 10-inch screw conveyors. The seed is fed into one end of the top conveyor and is discharged at the opposite end of the bottom conveyor. Immediately underneath each conveyor is a partly inclosed steam pipe. In the upper side of this pipe are a number of small perforations through which

[17] R. E. McDonald, and G. J. Scholl. Op. cit.

[18] In experiment No. 258, a temperature of 145° F. was reached, but the mortality was less than 100 per cent. It will be noted, however, that the exposure was only 2¼ minutes.

[19] Later experiments have shown that the capacity of the machine can be increased indefinitely by increasing its size.

steam is injected directly into the moving seed mass in the conveyor. A regulating valve controls the quantity of steam passing into the conveyors, and other valves serve to cut off the steam from any of the conveyors altogether, if desired. A thermometer with the bulb fixed near the discharge end of the machine records the temperature of the seed as it passes out of the machine.

In testing this machine it was learned that the seed is very unevenly heated while passing over the perforated pipes. Some seeds are hit directly by a jet of steam; others pass entirely through the conveyor without being hit directly. But at the same time the vapor is thoroughly mixed with the seed. When the seed is run directly from a heated conveyor into a sack, the temperature immediately rises very high, but soon drops again. The first high reading evidently is due to the vapor and the hot outside walls of the seed. When the seed is left in bulk for a short time, this heat penetrates to the inside of the individual seeds, causing a lower but more even temperature throughout the seed mass, and a consequent falling of the temperature. If this is true, it explains the fact that treatment in a single conveyor, even though giving a temperature in a sacked sample high enough to kill the pink bollworm, fails to kill if the seed is immediately cooled.

A number of series of tests were conducted with this machine operated at different speeds and steam pressures, and with steam injected into different conveyors. The procedure followed was similar to that with the dry-heat machine. The machine was fed by hand. Samples for examination were caught on a screen and immediately cooled, the double seed picked out and examined. Between each two samples for examination, a sample for temperature readings was taken. Thus in the records, with a few exceptions, two temperatures are given for each test, as in the tests with the other machine.

The results of these tests are given in Table 44.

TABLE 44.—*Results of treatment of cottonseed in live-steam disinfecting machine*

SERIES 1

[Speed of machine, 42 revolutions per minute. Time of exposure, 1 minute 5 seconds. Steam admitted into two upper conveyors only]

Test No.	Number of larvæ in tests	Seed temperature on discharge	Larvæ killed	Test No.	Number of larvæ in tests	Seed temperature on discharge	Larvæ killed
		°F.	Per cent			°F.	Per cent
18	6	136 -141	100	45	56	145 -149	100
47	65	143 -137	100	42	69	146 -145½	100
41	10	140 -138	80	34	42	151 -145½	100
19	7	141 -140	100	11	14	146	100
40	17	144½-140	100	23	22	148	100
37	11	141 -143	100	25	55	148	100
44	44	141 -145	100	22	20	150 -148	100
36	13	145 -141	100	13	6	148½	100
43	47	145½-141	100	21	16	149 -150	100
15	7	145½-141½	100	12	4	150	100
16	5	141½-146	100	24	54	150	100
14	8	142	100	28	54	150 -152	100
48	43	142½	[1] 97.6	27	41	154 -150	100
38	15	143 -144	100	33	33	152 -151	100
46	38	149 -143	100	30	48	154 -151	100
20	18	144	100	31	42	151 -155	100
39	13	144 -144½	100	29	56	152 -154	100
26	32	144 -154	100	32	46	155 -152	100
35	14	148 -145	100	17	5	153 -154	100

[1] The only living larva found in this sample was crawling on the treated sample and probably had not passed through the machine.

TABLE 44.—*Results of treatment of cottonseed in live-steam disinfecting machine*—Continued

SERIES 2

[Speed of machine, 50 revolutions per minute. Time of exposure, 55 seconds. Steam admitted into two upper conveyors only]

Test No.	Number of larvæ in tests	Seed temperature on discharge	Larvæ killed	Test No.	Number of larvæ in tests	Seed temperature on discharge	Larvæ killed
		°F.	Per cent			°F.	Per cent
52	103	138	100	55	141	146 –145	100
51	115	138 –138	100	53	98	145 –147	100
50	56	141 –138	100	123	44	145½–148	100
121	39	138½	94.8	120	40	146	100
127	22	139	100	54	84	147 –146	100
117	36	141	100	125	43	146½–147	100
49	89	149 –141	100	124	32	148 –146½	100
128	28	141½	100	122	27	147	100
118	33	142	100	126	32	147 –147	100
57	109	143 –142	99	119	22	149½	100
56	118	145 –143	100	130	24	152 –152½	100
129	26	144 –152	100	131	27	152½–152	100

SERIES 3

[Speed of machine, 55 to 56 revolutions per minute. Time of exposure, 49 seconds. Steam admitted into two upper conveyors only]

		°F.	Per cent			°F.	Per cent
106	46	140	100	109	32	152 –149	100
105	73	141 –140	100	108	57	150	100
104	101	146 –141	99	111	48	150 –155	100
102	61	145	100	114	50	151½–152	100
103	61	149 –146	100	113	24	153 –151½	100
116	44	148 –150	100	107	57	152	100
115	82	152 –148	96.3	112	43	155 –153	100
110	43	149 –150	100	101	57	154	100

SERIES 4

[Speed of machine, 60 revolutions per minute. Time of exposure, 47 seconds. Steam admitted into two upper conveyors only]

		°F.	Per cent			°F.	Per cent
58	143	136 –140	100	90	52	143 –145	100
98	91	138	90.9	92	42	146 –143½	100
99	57	138 –140½	94.7	95	41	149 –143½	100
100	61	140½–138	100	84	42	144 –145	97.6
62	108	141 –138	87.9	83	28	147 –144	100
73	62	138 –142	100	69	89	149 –144	100
72	85	143 –138	98.8	91	49	145 –146	100
85	45	145 –138	91	64	33	145 –146	100
86	32	138 –146	84.3	63	34	149 –145	100
71	94	142 –139	98.9	93	33	145½	100
82	33	139 –147	100	94	50	146	100
81	36	149 –139	97.1	65	68	146 –149	100
59	111	140 –141	94.5	68	49	149 –149	100
88	21	140½	95.2	66	46	149 –150	100
80	29	140 –149	100	67	60	150 –149	100
60	75	141 –142	100	75	82	152 –153½	100
61	57	142 –141	98.2	74	83	155½–152	100
97	67	142	100	78	47	153 –154	100
70	76	144 –142	97.3	77	60	155 –153	100
87	53	146 –142	98.1	76	70	153½–155	100
89	29	142½	100	79	30	154	100
96	30	143½–143	100				

SERIES 5

[Speed of machine, 40 revolutions per minute. Time of exposure,[1] 1 minute 8 seconds. Steam admitted into two lower conveyors only]

		°F.	Per cent			°F.	Per cent
138	27	137	81.4	141	76	144	84.2
135	22	138	100	134	20	154	100
139	30	138–142	93.9	136	28	160	96.4
142	59	139	89.8	132	33	162	100
137	36	140	100	133	37	166	100
140	64	142–147½	73.4				

[1] Actual exposure is only about 46 seconds on account of no steam reaching the seed until it entered the second section of conveyor.

TABLE 44.—*Results of treatment of cottonseed in live-steam disinfecting machine*—Continued

SERIES 6

]Speed of machine, 40 revolutions per minute. Time in machine, 1 minute 8 seconds. Steam admitted into top conveyor only]

Test No.	Number of larvæ in tests	Seed temperature on discharge	Larvæ killed	Test No.	Number of larvæ in tests	Seed temperature on discharge	Larvæ killed
		°*F.*	*Per cent*			°*F.*	*Per cent*
165	26	137 –135	100	169	18	154 –146	100
163	16	136 –137	100	151	9	147 –147	100
162	30	142 –136	100	150	26	151½–147	100
164	8	137 –137	100	157	26	148	100
143	20	139	100	166	24	148	100
175	28	139½–140	100	145	14	148 –148	100
174	21	140 –139½	100	155	27	149 –148	100
173	22	140 –140	100	154	39	149	100
172	13	142 –140	100	144	21	149½	100
161	53	142 –142	100	146	17	150	100
159	29	142 –143	100	153	20	151½	100
160	19	143 –142	100	149	10	153 –151½	100
158	26	146 –142	100	167	18	153	100
171	20	147 –142	100	168	28	153 –154	100
170	33	143	100	148	24	157½–153	100
152	32	147 –144	100	147	24	158 –157½	100
156	29	148 –146	100				

SERIES 7

[Speed of machine, 50 revolutions per minute. Time of exposure, 55 seconds. Steam admitted into top conveyor only]

		°*F.*	*Per cent*			°*F.*	*Per cent*
186	17	138 –132	82.3	191	16	147 –140	100
178	25	133½–135	96	187	7	141½	100
179	17	135 –153	100	195	11	142½–146	100
177	33	136	96.9	194	8	147 –142½	100
176	13	136	100	182	13	143 –145	100
185	31	138 –138	100	181	22	151½–143	100
192	17	140 –138	94	190	10	144 –147	100
184	29	140 –138	100	189	15	147 –144	100
193	13	138 –147	100	188	13	147½	100
183	20	145 –140	100	180	19	153 –151½	100
196	11	146 –140	100				

SERIES 8

[Speed of machine, 60 revolutions per minute. Time of exposure, 47 seconds. Steam admitted into top conveyor only]

		°*F.*	*Per cent*			°*F.*	*Per cent*
206	8	138	100	200	10	143–143	100
207	10	139	100	201	16	143–145	93.7
208	16	139–140	93.7	199	10	145–143	100
209	16	140–142	100	205	22	150–143	100
213	30	141–141	100	218	22	150–143	100
214	22	141–141	100	197	10	144	100
215	25	141–141	100	198	9	145	100
219	15	143–141	100	202	9	145–147	100
212	12	144–141	100	203	12	147–147	100
216	18	141–150	100	204	13	147–147	100
210	20	142–142	100	217	10	150–150	100
211	17	142–144	100				

The record of time of exposure in all the series referred to the time required for the seed to pass entirely through the machines, regardless of which conveyors it was exposed to steam in. It was the purpose to show in these tests a range of temperatures from which the safe minimum temperature giving 100 per cent mortality at a given time of exposure might be determined. Owing to irregular boiler

pressure and feeding, however, it was difficult to obtain a certain desired temperature in any one test, and the temperatures obtained in any series were usually very irregular. To this same irregularity in steam pressure and feeding can be ascribed the wide variations in temperature indicated in some of the individual samples.

In the tests recorded in series 1, 2, 3, and 4 steam was admitted into the upper two conveyors of the machine only. The results in these four series show the maximum temperatures that failed to give 100 per cent mortality for the respective periods of exposure to be as follows:

Series 1, 1 minute, 5 seconds, 142½° F.
Series 2, 55 seconds, 143° F. to 142° F.
Series 3, 49 seconds, 152° F. to 148° F.
Series 4, 47 seconds, 144° F. to 145° F.

In series 5 steam was admitted into the two lower conveyors only and the seed required 1 minute and 8 seconds to pass through the machine. This would of course be equivalent to a machine with two conveyors only and an exposure of about 46 seconds. In series 6, 7, and 8 steam was admitted into the top conveyor only. The results in these series show the maximum temperatures that failed to give 100 per cent to be as follows:

Series 5, 1 minute, 8 seconds (46 sec.), 160° F.
Series 6, 1 minute, 8 seconds (all 100 per cent).
Series 7, 55 seconds, 140° F. to 138° F.
Series 8, 47 seconds, 143° F. to 145° F.

These eight series throw considerable light upon the action of a machine of this type. In series 1 and series 5 the time of exposure is the same, or practically the same, and in each steam is admitted into two sections of conveyor. Under equal pressure this should heat the seed equally. Yet series 5 shows a failure at 160° F., and in series 1 142½° is the maximum that did not give 100 per cent mortality, and it is a doubtful record. Other tests in series 5 compare with those in series 1 in a similar way. This brings out the point already mentioned, that the record obtained immediately after exposure does not show the temperature attained by the inside of individual seeds.

From this it may be concluded that, in the test in series 5, enough steam had been injected into the seed mass to raise the seed to a temperature sufficient to kill the pink bollworm, were it bulked long enough to allow even heating throughout the mass by absorption. This at the same time explains the better results obtained when steam was admitted into the upper conveyors only, giving opportunity for absorption of heat while the seed was passing through the lower dry conveyors.

The results obtained in these tests warrant the conclusion that a machine of this type will be successful if operated so that the seed is discharged at a temperature of not less than 145° F. after an exposure of at least one minute, during the first half of which it is subjected to steam, the remaining time being allowed for penetration of the heat to the larva inside the seed. The temperature record should be obtained at a point near the discharge end of the machine.

EFFECT OF LIVE-STEAM TREATMENT ON GERMINATION

A number of germination tests with samples taken from the series of tests just discussed were made. The results are given in Table 45.

These tests were conducted a few days after the seed was treated. They show plainly that the treated seed was not damaged when cooled immediately.

TABLE 45.—*Percentage of germination of seed after treatment in live-steam machine*

Seed temperature on discharge	Time in machine	Germination: Heated seed	Germination: Check seed	Seed temperature on discharge	Time in machine	Germination: Heated seed	Germination: Check seed
°*F*	*Min. sec.*	*Per cent*	*Per cent*	°*F*	*Min. sec.*	*Per cent*	*Per cent*
136 -140	47	77	77	146	1 20	85	87
143	1 20	89	87	146	1 20	90	87
143 -145	55	80	85	148	1 20	82	76
144 -147	55	87	85	149.5	1 8	88	85
145.5-141.5	1 5	84	85	150	1 20	79	76
145	1 20	79	76	150	1 5	92	91
145	1 20	81	87	151 -145.5	1 5	80	78
145	1 20	87	87	152.5-152	55	81	80
145	1 20	89	76	160	46	77	80
145	1 20	89	76				
145.5	47	83	79	Average		83.9	82.0

An experiment was performed to determine the time required for seed to cool if bulked immediately after treatment. Several tons of seed were treated, admitting steam only into the top conveyor, and bulked in the corner of the seed house. The seed registered a temperature on discharge ranging from about 140 to 152° F. After bulking, a recording thermometer was inserted into the seed pile. The readings obtained are shown graphically in Figure 13. A curve showing the mean daily outside air temperature during the period is also given. The difference between the temperature at discharge and that after bulking was probably caused by absorption of heat after leaving the machine and by loss incurred while the seed was carried in sacks and emptied in the corner of the seed house.

Germination tests of some of this seed were made, using one untreated sample, one treated sample that was cooled immediately, and one sample that was kept in bulk from December 15 to 30. These germination tests to date of this writing (April, 1923) resulted as shown in Table 46.

TABLE 46.—*Percentage of germination of seed treated in live-steam machine*

Sample	January, 1923	February, 1923	March, 1923
	Per cent	*Per cent*	*Per cent*
Check	85	94	98
Cooled immediately	86	94	93
Bulked Dec. 15 to 30	87	92	97

According to the above results, no harm follows bulking of seed immediately after treatment with live steam.

AMOUNT OF MOISTURE ABSORBED BY SEED IN LIVE-STEAM TREATMENT

Several tests were made with the live-steam machine to determine the amount of water absorbed by seed on treatment. Quantities of seed were weighed before treating and again after treating. The results are given in Table 47.

TABLE 47.—*Absorption of moisture by seed treated in live-steam machine*

Time in machine	Steam pressure	Weight of seed— Before treatment	Weight of seed— After treatment	Gain in weight	
M. sec.	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Per cent*
1 5	50	1,137	1,172	35	3.08
1 5	50	781	814	33	4.2
55	55	782.8	804	21.2	2.7
55	70	846.6	861.2	14.6	1.7

In the first three tests steam was admitted into two sections of the conveyor, and in the last into only one. The temperatures recorded in these tests ranged from 144 to 150° F. It appears from the results

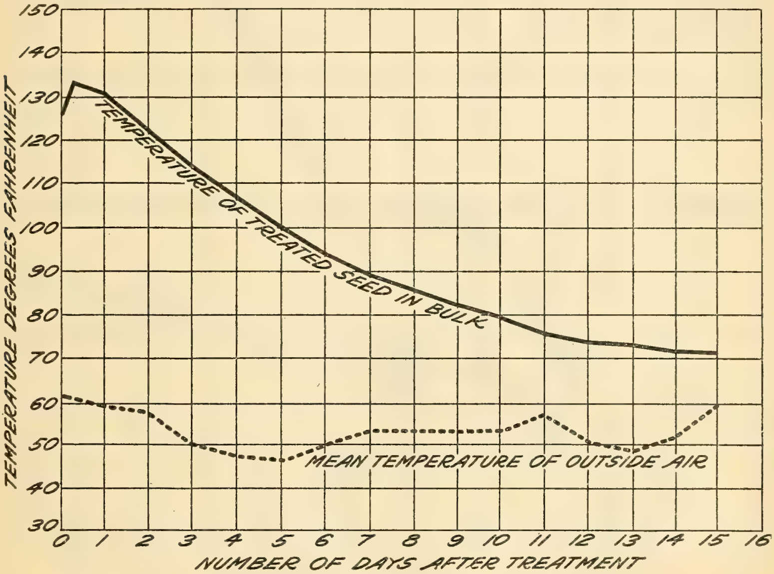

FIG. 13.—Cooling of seed treated with live steam and bulked immediately after treatment

that the amount of moisture absorbed decreases when the time of actual subjection to steam is reduced, even though the steam pressure has to be increased to give sufficient heat.

PRACTICAL USE OF DISINFECTING MACHINES

Under the State regulations, disinfecting machines were installed at all the gins during 1922 in all of the regulated zones in Texas. Twenty-three of these machines were of the dry-heat type and 14 of the live-steam type. Altogether about 23,000 tons of seed were treated. There were no interruptions and machines were found to be entirely practicable.

Dry-heat machines costing about $500 each had a capacity in the larger size as high as 10 bushels per minute. Three horsepower was required to operate this machine. The expense of operation ranged from 10 to 25 cents per ton of seed.

The live-steam machine was found under practical working conditions to have a capacity of 5 bushels per minute and required not more than two horsepower. The cost of operation was about the same as in the case of the dry-heat machine.

Continuous series of germination tests were made during the operation of these machines. There were no indications of any appreciable reduction in the vitality of the seed.

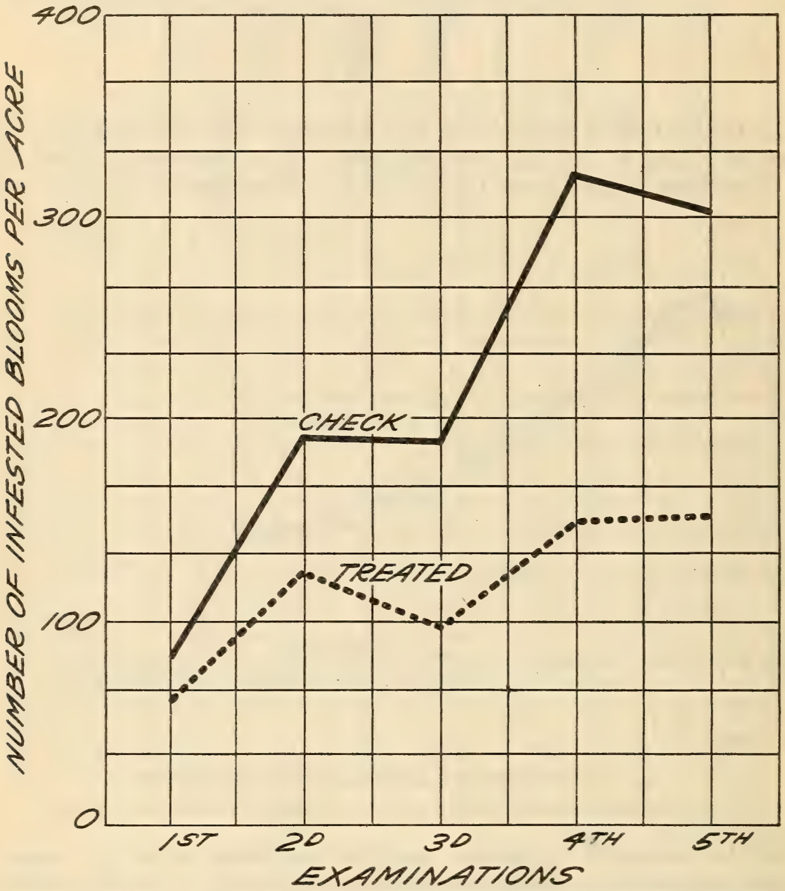

FIG. 14.—Number of infested cotton blooms per acre in poisoned and check plats, 1921 experiments, as shown by weekly examinations. First examination made six days after treatment began

POISONING EXPERIMENTS

The habits of the newly hatched pink bollworm larva suggest that there may be an opportunity to kill it by means of poison before it enters the boll or while it is attempting to enter. Experiments were instituted at Tlahualilo to determine whether any degree of control could be attained by dusting with arsenical poisons.

In 1921, nine separate plats in large cotton fields were treated, seven of these with calcium arsenate and two with arsenite of zinc. Records were kept at the same time on an equal number of check plats of equal size. As the purpose of these first experiments was to determine whether any control could be attained, no attempt was

made to do the work on a commercially profitable basis. On the contrary, the plan followed was to keep the plants thoroughly covered with poison during the entire period of treatment. Some of the plats were dusted with hand guns and others with 2-row mule dusting machines.

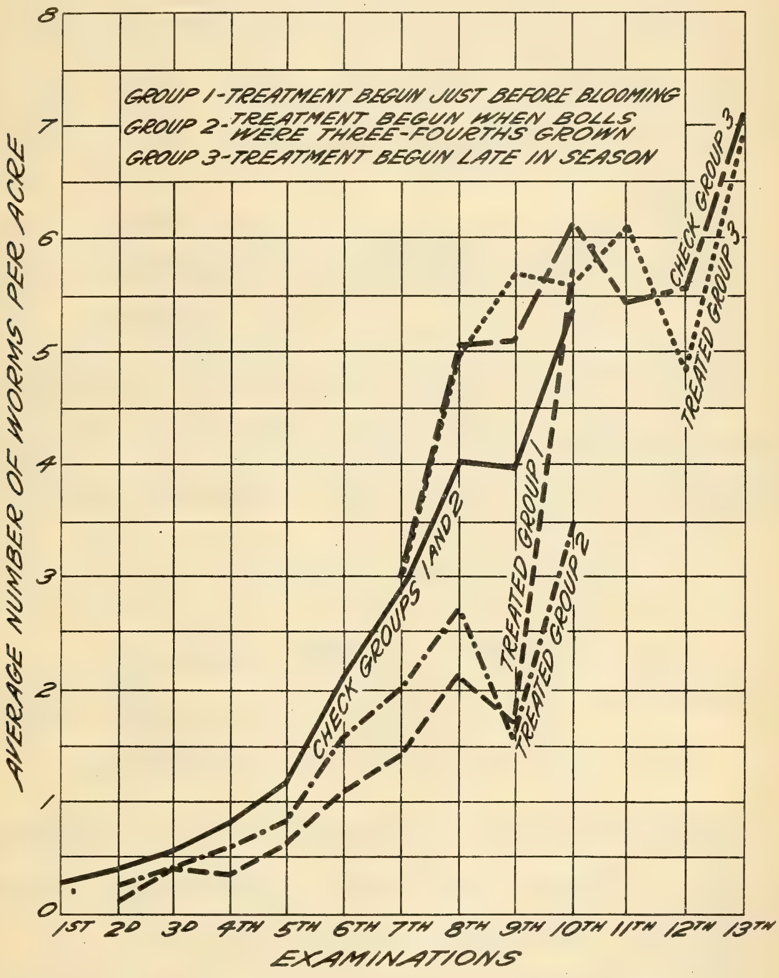

FIG. 15.—Progress of the infestation of green bolls in poisoned and check plats as shown by weekly examinations, 1921 poison tests

The air in the Laguna district is very dry and there is considerable wind. It was therefore found that applications must be made every five days in order to keep the plants fairly well covered with poison. Applications were repeated after rains. A period of calm lasting an hour, more or less, usually occurs at 5 or 6 o'clock in the morning, and the applications were made at that time. Dew was usually absent or so light as to be hardly noticeable. The conditions for dusting were therefore far from ideal.

The 1921 plats may be divided into three groups. Poisoning on those of the first group (plats 2, 6, 10, and 14) began about the middle

of June, a few days before blooming started. Treatment of the plats in the second group (plats 4, 8, 12, and 16) began in the latter part of July. At that time the first bolls were about three-fourths grown. In the third group (plat 18) poisoning began near the end of August, when the infestation averaged 2.96 worms per boll. Applications were continued on all plats until nearly all bolls were open.

In the beginning, records of infestation were obtained by examining blooms. But after bolls developed this record was replaced by boll examinations, which were made weekly. Figure 14 shows the development of the infestation in blooms in the plats of group 1 and the corresponding check plats. According to this record the treatment caused a very noticeable check in the infestation.

The progress of boll infestation, by groups of plats, is shown graphically in Figure 15.

A general summary of the experiments is given in Table 48. These records show definitely that the infestation was reduced by poisoning. The earlier the treatment was commenced the greater the reduction obtained. Treatment begun very late had practically no effect, as shown in Group 3, plats 17 and 18. The sudden rise in numbers, of worms per boll in the plats of Group 2 (fig. 15) at the last examination was due to scarcity of bolls. Very few bolls were left on the plats at this time. This, however, was an abnormal record, not comparing with the previous showing of the plats. In the table, therefore, the next to the last instead of the last examination is given for plats 13, 14, 15, and 16, to show the maximum reduction in infestation due to the treatment.

TABLE 48.—*Summary of poisoning tests, 1921*

Plat No.	Treatment	Acres	Date of application		Number of applications	Pounds applied		Infestation last examination		Percentage non-pickable cotton	Classification of lint samples
			First	Last		Total	Per acre	Worms per boll	Percentage difference		
1	Check	1						3.46		9.3	Middling.
2	Calcium arsenate.	1	June 15	Aug. 23	16	152.5	9.5	1.92	44.5	3.3	Strict middling.
3	Check	1.11						3.82		6.9	Do.
4	Calcium arsenate.	1.11	July 20	Aug. 23	8	84.75	9.5	2.88	24.6	5.3	Good middling.
9	Check	1						3.22		8.0	Do.
10	Calcium arsenate.	1	June 15	Aug. 23	16	124.25	7.8	2.44	24.2	6.0	Do.
11	Check	1.11						4.04		7.7	Strict middling.
12	Calcium arsenate.	1.11	July 20	Aug. 23	8	84.75	9.5	3.72	7.9	7.5	Do.
13	Check	1.07						[1] 4.16		11.0	Do.
14	Calcium arsenate.	1.07	June 25	Sept. 14	19	181.25	8.9	[1] 1.66	60.1	6.8	Good middling
15	Check	1.07						[1] 3.68		9.0	Strict middling.
16	Calcium arsenate.	1.07	July 24	Sept. 14	12	112.0	8.7	[1] 1.52	58.7	4.5	Good middling.
17	Check	2.16						6.98		14.8	
18	Calcium arsenate.	2.16	Aug. 26	Sept. 30	9	229.0	11.8	6.8	2.6	10.8	
5	Check	0.66						4.8		6.7	Strict middling.
6	Arsenite of zinc.	0.66	June 15	Aug. 23	16	134.0	12.7	2.38	50.4	4.4	Good middling.
7	Check	0.66						4.18		7.0	Strict middling.
8	Arsenite of zinc.	0.66	July 19	Aug. 23	8	60.0	11.4	3.14	24.9	5.5	Good middling.

[1] These were the next to last examination.

Treatment of the cotton, particularly in the early plats, was followed by aphid infestation, which reduced the yield considerably. On this account the yields of the early-treated plats were for the most part lower than those of the check plats. There was a slight increase in yield of the treated plats of the second group.

Poisoning experiments were continued in 1922, but on a slightly different basis. Instead of making applications of poison on all plats till the end of the season, an equal number of treatments was given each plat, but during different parts of the season. Most of the plats were arranged in several six-plat series with two check plats to the series. Treatments on each series covered a period of 16 applications at five-day intervals. One such series then consisted of the following:

Plat 1, check.
2, first 7 applications.
3, applications Nos. 4 to 10, inclusive.
4, applications Nos. 7 to 13, inclusive.
5, applications Nos. 10 to 16, inclusive.
6, check.

Infestation records were kept on each plat throughout the season. In addition to the use of calcium arsenate and arsenite of zinc in different series, one entire series was treated with lead arsenate.

Although a considerable volume of data was obtained in the 1922 experiments, no very definite conclusions could be drawn other than those drawn from the 1921 experiments. The plats receiving the early applications showed a greater percentage reduction in infestation during the period of treatment than later ones, amounting in some individual examinations to more than 50 per cent. But after the period of treatment the infestation rose again. The later applications on the other hand caused a greater reduction in actual number of worms per boll, and an average of all the examinations in each plat showed a lower number of worms per boll in the later plats. This point is illustrated in Table 49, in which are summarized data from 2 complete and 1 incomplete 6-plot series.

TABLE 49.—*Summary of Series D, E, and G, 1922 poison tests*

Plat No.	Poison applications	Average number of worms per boll per examination	Daily average number of blooms per acre		Bolls per plant		Yield (pounds per acre)			Percentage non-pickable cotton
			First crop	Second crop	First picking	Second picking	First picking	Second picking	Total	
1 and 6	None	3.89	6,211	2,939	5.17	2.22	1,062	48	1,110	13.4
2	First 7	3.07	6,676	2,592	5.97	2.02	1,275	69	1,344	10.6
3	4 to 10, inclusive	3.04	6,687	3,363	5.56	2.54	1,172	142	1,314	13.2
4	7 to 13, inclusive	3.00	6,341	3,302	5.80	2.91	1,074	186	1,260	11.5
5	10 to 16, inclusive	2.89	6,128	3,154	5.50	3.04	1,076	138	1,214	13.3

Aphid damage in 1922 was checked by dusting with nicotine sulphate preparations. As many as three applications were necessary on some of the series. Whenever an application on one plat became necessary, all plats in the series were treated, checks included, so that any action of the nicotine on the pink bollworm would be the same for all plats.

The records show increases in yield for all the treated plats, the increase being greatest in the plats that received early treatment. Records of blooming and bolls produced should be considered in connection with the yields. Bloom counts were made weekly in each plat, and bolls were counted just before the first pick and shortly before the second pick. The individual plat averages for both blooms and bolls of the first crop are comparable among themselves about as the yields of the first pick in the same plats. This holds true, more or less, also with the second crop of blooms and bolls and the yields of the second pick. According to these records the increase in yield of the treated plats can not be ascribed entirely to reduction of the pink bollworm damage, but the poisoning evidently reduced the infestation.

Each boll count represents an average from 50 plants at each of 3 points per plat. The count of the first crop of bolls included only bolls that were open just before the first picking. All of the first-crop bolls were open at this time, but hardly any of those of the second crop. Boll counts for the second crop were made several weeks before the second picking and included both open and nearly grown green bolls. No doubt the shedding of some of these green bolls and the failure of others to open by the time of the second picking, the smaller size of the bolls of the second crop, and the non-pickable cotton practically all of which was of the second growth, all contributed toward the much greater difference that is found between the yields of the first and the second picking than that found between the records of total bolls of the first and of the second crop.

Of three other series of poison tests conducted in 1922, two showed increases in yield in treated plats. In the third there was a very slight decrease.

COMPARATIVE EFFECTIVENESS OF DIFFERENT POISONS

Reduction in infestation was brought about by all three poisons used in 1922. Sufficient experiments have not been made to determine whether one is more effective than the others. Because the 6-plat series treated with arsenite of zinc was left incomplete, a comparison of the effectiveness of the three kinds of poison can be based only on the results obtained in the two latest poisoned plats in each of three 6-plat series on which different poisons were used. This comparison of the poisons is shown in Table 50.

Table 50.—*Comparison of average infestation in plats treated with different kinds of poison*

Plat No.	Treatment	Average number of worms per boll per examination		
		Calcium arsenate	Arsenite of zinc	Lead arsenate
1 and 6	Check	[1] 5.13	[1] 5.13	[1] 5.13
4	Aug. 9 to Sept. 7	4.29	4.30	4.19
5	Aug. 22 to Sept. 26	4.07	4.17	4.15

[1] Average of checks, all series.

The differences here are so slight that the effectiveness of all the poisons must be considered about the same. In the records for 1921 (Table 48, plats 2, 4, 6, and 8) the effectiveness of calcium arsenate and that of arsenite of zinc compare in a similar wav.

ACTION OF THE POISON ON THE PINK BOLLWORM

In the fall of 1922 experiments were begun to determine the manner in which the application of arsenicals to cotton reduces the pink bollworm infestation. It was planned to determine by applications of dust, in one case to the entire plant except the bolls, and in another to the bolls only, whether the young larvæ are killed while they feed on the foliage or while they attempt to enter the boll. A few plants were selected for each test and young bolls on them labeled, including bolls on separate plants to serve as checks. Applications of dust were made every five days and repeated after rains. An examination of 50 small bolls as a check at the beginning of the experiment showed an average of 0.38 worm per boll. The results of this experiment are summarized in Table 51.

TABLE 51.—*Effect on pink bollworm infestation of the application of calcium arsenate dust on bolls only and on the rest of the plant only*

Part of plant dusted	Period of treatment	Number of bolls	Eggs and eggshells on bolls			Larvæ and exit holes		Dead larvæ in bolls
			Total eggs	Total egg-shells	Average per boll	Total	Per boll	
Entire plant except bolls	Sept. 1 to 30	100	3	96	0.99	209	2.09	13
Check	None	82	46	227	3.33	277	3.38	17
Bolls only	Sept. 1 to Oct. 3	50	4	30	.68	185	3.70	6
Check	None	58	55	242	5.12	256	4.41	9
Average, both checks					4.07		3.80	

Reduction in infestation was brought about in both cases, but it was more marked where the foliage was dusted than where the bolls only were dusted. It would appear that young larvæ were killed both while feeding on the foliage of dusted plants and while entering the bolls. But the most striking point in the results is the great reduction in the number of eggs found on the bolls after dusting. This was found to be the case also in the examination of bolls from plats in the other poison tests. It suggests that the reduction in infestation may not have been brought about at all by killing of the larvæ, but by repelling the moths. This point should be closely studied in connection with further dusting experiments.

SUMMARY

An average annual loss of from 20 to 25 per cent of the cotton crop has been caused by the pink bollworm in Mexico, since the infestation attained maximum development. There is a reduction in both the quantity of the total crop picked and the quality of the lint and seed marketed.

The pink bollworm begins its attack on the early squares. From this beginning the numbers of the insect increase with regularity until at the height of the season four or more larvæ per boll is a common average and all late bolls are rendered practically valueless. The enormous numbers of larvæ that go into hibernation in stored seed and in the bolls and soil in the field insure the presence of sufficient adults to begin the attack the following spring.

In the summer the larva leaves the boll to pupate. About 80 per cent pupate in the soil, the remainder in and under plant material on the surface of the soil. (Table 3.) The majority of the larvæ are found within the first 2 inches of soil (Table 4), and more of them immediately under the plants than between the rows (Table 5). As many as 83 living larvæ and pupæ have been found in 1 square yard of soil. (Table 6.) Some larvæ hibernate in the soil. In some instances over 20 living larvæ were found per square yard of soil in the field in winter. (Table 7.)

The common manner of dispersal is through the carriage of infested seed by man. Experiments have shown that isolated plantings of cotton even as far as 40 miles from the nearest source of infestation readily became infested where chances of carriage by man were meager but by no means excluded.

The mortality among newly hatched larvæ is great (p. 31). Of the larvæ entering the soil for pupation during the summer, 19.7 per cent were found to die (p. 32). The attacks of parasites on the pink bollworm in Mexico are spasmodic and as yet have not proved of any importance (p. 36). The mortality of resting larvæ in the field during winter and early spring is great, and when fields are flooded in winter hardly any survive. (Table 28.)

When fields are cleaned in fall and winter and bolls that are shed remain on the soil, many larvæ leave these bolls and enter the soil for hibernation. (Table 37.) The survival of larvæ during the winter is much greater in bolls on stalks in the field than in bolls on the surface of the soil (Tables 8 and 9), showing plainly the advantage of cutting and burning old stalks.

The pink bollworm may be killed in cottonseed by heat without injury to the seed. Machines have been made in which the seed is treated either by dry heat or by contact with live steam. By the first method, seed can be disinfected by heating to a temperature of 145° F. in 3½ minutes. By injection of live steam into the seed mass the time of exposure required can be lessened.

The infestation of green bolls has been reduced as much as 60 per cent (Table 48) by repeated applications of arsenicals in the field. This indicates that there is some hope for practical control by this means, but a final conclusion on this point depends on future work.

O